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Founded 1896 by L. A. BAUER *Continued 1928-1948 by* J. A. FLEMING

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THE DISTRIBUTION OF GREAT AND SMALL GEOMAGNETIC STORMS IN THE SUNSPOT CYCLE

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(Received September 9, 1953; communicated by the Astronomer Royal)

ABSTRACT

The distributions of (1) great geomagnetic storms, (2) small storms with "sudden commencement" (SC), and (3) small non-SC storms through the sunspot cycle are examined. There is a close accordance between the averaged sunspot curve for the past seven cycles and the averaged curve for geomagnetic storms (1) and (2), which is shared by the giant sunspots, solar flares of greatest magnitude, and notable auroral displays. For the small non-SC storms, the distribution within the sunspot cycle and also the extent of the relationship with sunspots at storm onset differ from those of the previous phenomena. The broad division of small storms according to the SC criterion appears to be of intrinsic significance (probably related to their solar origin), since this division is supported by the differences found in (1) distribution in the sunspot cycle, (2) relation to sunspots, and (3) characteristics (in addition to the SC criterion), including a statistical difference in the tendency to recur at intervals of a synodic rotation (27 days), as announced by E. and O. Thellier in 1948 and confirmed in the present paper. The Greenwich analysis of 1928, showing the statistical non-recurrence of great storms, is brought up to date.

The distribution of geomagnetic storms, without regard to magnitude and type, shows only a rough accordance with the 11-year sunspot cycle, and at times any connexion is obscure. For instance, in 1952—barely two years before the

expected sunspot minimum of the present cycle—there were recorded at Abinger no fewer than 19 magnetic disturbances exceeding the lower limit adopted for a small storm, and in addition another storm rising just above the lower limit for a "great" storm. Five years earlier, at the time of the abnormally high sunspot maximum, the total number of storms recorded was one fewer than in 1952, but five of these were great storms.

It is the purpose of this note, using Greenwich data from the last seven sunspot cycles,

(1) To show the clear (statistical) relationship between the distribution of great geomagnetic storms and the averaged sunspot curve:

(2) To compare this distribution with those given by two categories of small storms, (*a*) with sudden-commencement (SC) onset, and (*b*) with non-SC and indefinite onset;

(3) To present briefly, as being particularly relevant to the occurrence of great geomagnetic storms, the comparative distribution of notable aurorae, giant sunspots, and intense solar flares.

Great Geomagnetic Storms

The occurrence of a great geomagnetic storm appears to be primarily related to the occurrence over a sunspot of an antecedent flare of high intensity, usually within the central half of the Sun's disk. Statistical results show also that the occurrence of such a flare is partly determined by the size of the associated sunspot, its stage of development, and its type (distribution of magnetic polarities). A favourable combination of these factors is unlikely to happen often, though more than one major flare may occur over a particular sunspot.

Great magnetic storms are likewise infrequent, averaging 15 or 16 per sunspot cycle. Significantly, they tend to group themselves in time, two or sometimes three great storms being separated by only a day or two [see 1 of "References" at end of paper]. Extended data will therefore be required to derive their typical distribution within the sunspot cycle.

Lists of storms, together with comparative sunspot data, are available for seven cycles, collectively in *Greenwich Photoheliographic Results*, 1927, p. 131, and in annual additions to date in *The Observatory*.

From the beginning (1878.9) of the first cycle considered, 110 great storms have been listed up to the present date, when the seventh cycle has nearly run its course.

The lower limit adopted at Greenwich for a great storm is 60′ in declination (D) or 300γ in horizontal intensity (H) or in vertical intensity (Z). This limit is admittedly arbitrary, but it appears to have been fairly well chosen, since later classifications have shown that at Greenwich, "M-region" storms (see infra) seldom exceed this limit, though they may closely approach it.

The distribution of these 110 great storms, presented in Figure 1, has been obtained by summing the number of storms over the seven spot cycles in each 12-monthly period, extending from the epoch of maximum of each respective cycle. These epochs of sunspot maxima given by Zurich are 1883.9, 1894.1, 1907.0, 1917.6, 1928.4, 1937.4, and 1947.5. The number of storms in each 12-monthly

interval, extending from 3.9-3.0 years before maximum to 6.0-6.9 years after maximum, has then been expressed as a percentage of the whole (110 storms).

For comparison, the averaged sunspot curve* has been derived in the same manner as described above, from monthly values of the mean daily sunspot "num-

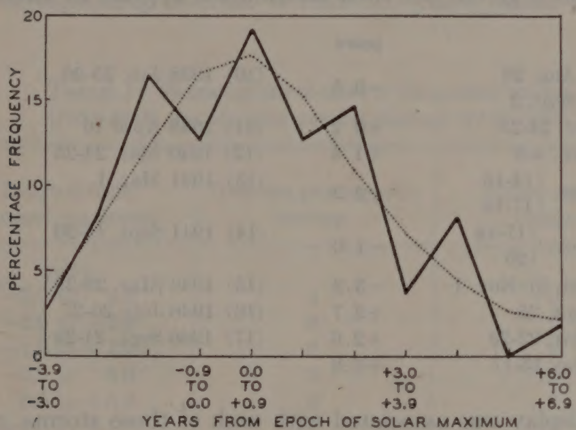

Fig. 1—Distribution of great magnetic storms in the sunspot cycle, 1878.9–1952.5, 110 storms [full curve for great magnetic storms; dotted curve for mean sunspot "numbers" (Zurich)]

ber" published from Zurich. There is good agreement between the averaged curves given by spot "numbers" and Greenwich sunspot areas.

The 12-monthly values for the combined cycles lie practically on a smooth curve, as might be expected from the amount of data, with a rise from minimum to maximum in about four years, and a fall from maximum to minimum in about seven years.

Turning to the distribution of the great storms, we see that the smoothed curve that could be put through the points is virtually that of the averaged sunspot curve, so that it may be concluded that the origin of great magnetic storms has a direct, one-parameter relation to the sunspot cycle. Thus, at any epoch, the probability of a great storm occurring is proportional to the existing degree of spot frequency, or spotted area. This is, of course, a statistical result, and departures are to be expected in individual years, in view of the known relationships between great storms and sunspots involving the size of spots, their tendency to produce intense solar flares (a feature itself related to the age of the spot [2]), and the favourable combination of these features in the central half of the Sun's disk.

The Greatest Storms and Notable Auroral Displays

Of the 110 great storms during the past seven sunspot cycles, there are at least 13 storms of outstanding intensity [3]. The average ranges of these are $2^\circ.4$ in D: 1180γ in H, and 790γ in Z. These are minimum values, since in some cases,

*Figs. 1 to 3 should really be in the form of frequency polygon diagrams, but the graphical form is more convenient for these comparisons.

prior to the introduction of the La Cour records in 1938, the maximum ranges were lost. The dates of these storms are given below and in addition four storms of comparable intensity from the two preceding sunspot cycles, beginning with the minimum at 1856.0. In each case, the time-interval in years from the respective sunspot maximum is given, and their distribution appears in Table 1.

	years		*years*
(1) 1859 Aug. 28 / Sept. 2	−0.5	(10) 1938 Jan. 25-26	+0.7
(2) 1870 Oct. 24-25	+0.2	(11) 1938 April 16	+0.9
(3) 1872 Feb. 4-5	+1.5	(12) 1940 Mar. 24-25	+2.8
(4) 1872 Oct. 14-16 / 17-18	+2.2	(13) 1941 Mar. 1	+3.8
(5) 1882 Nov. 17-18 / 20	−1.0	(14) 1941 Sept. 18-20	+4.3
(6) 1903 Oct. 31-Nov. 1	−3.2	(15) 1946 Mar. 28-29	−1.3
(7) 1909 Sept. 25	+2.7	(16) 1946 July 26-27	−0.9
(8) 1920 Mar. 22-23	+2.6	(17) 1946 Sept. 21-24	−0.8
(9) 1921 May 13-17	+3.8		

An auroral display was associated with each of these storms, and in the cases of Nos. 1, 2, 3, 5, 8, 9, 10, and 14, the records indicate that each was exceptional, both in intensity and in extension to low latitudes. In the remaining cases, it is difficult to establish that the displays were not of great magnitude, because of the effect on the records of cloudy weather, duration and local time of darkness, and the presence of bright moonlight.

Table 1 may therefore be usefully supplemented by a selected list of outstanding displays, commencing with that of 1716 March 17 (New Style), which Halley described* [4] as the greatest aurora since that of 1574 recorded by John Stow in "English Annals." A selection of great auroral displays from 1716 to 1890 was made from "Les Aurores Polaires" by A. Angot (1895). In this work, the author did not attempt to give any indication of the magnitude of the aurorae, but it is not difficult to pick out the greater displays from the large number and southerly extent (in Europe) of the listed places from which such aurorae were seen. Using this rough criterion, a list of extensively observed aurorae (27 in all) was made, to which were added the outstanding displays recorded since 1890, namely, 1920 March 22-23, 1921 May 13-16, 1938 January 25-26, 1941 September 18-19, and 1949 January 24-25. The selection was made, of course, without any reference to the epochs of sunspot maximum.

The distribution of the epochs of these aurorae with respect to solar maximum is given in the last column of Table 1.

It will be seen from Table 1 that the distribution of the great auroral displays is similar to the averaged sunspot curve.† As regards the greatest geomagnetic

*Nearly 150 years later, Prof. E. Loomis, who collated the records of the great dual aurora of 1859 August 28 and September 2, wrote "This display was probably unsurpassed by any similar phenomenon on record, not only for its magnificence, but also for its geographical extent." [5]

†For a comparison between the auroral frequency at a single station and the sunspot curve, see H. H. Clayton, Terr. Mag., 45, 13 (1940).

storms, the statistics are insufficient to establish a characteristic distribution. The data do show, however, that over the period considered (1856-1952) no storm of comparable intensity occurred between the period extending from 2.5 years before to 2.1 years after any specific sunspot minimum. (In the case of the greatest aurorae, the corresponding interval is from 2.5 years before to 2.2 years after minimum.)

TABLE 1—*Frequency distribution of the greatest storms (1859-1952) and the great auroral displays (1716-1952)*

Interval from sunspot maximum	Greatest geomagnetic storms	Great auroral displays
years		
−3.9 to 3.0	1	0
−2.9 to −2.0	0	1
−1.9 to −1.0	2	2
−0.9 to 0.0	3	12
0.0 to +0.9	3	7
+1.0 to +1.9	1	4
+2.0 to +2.9	4	3
+3.0 to +3.9	2	2
+4.0 to +4.9	1	1
+5.0 to +5.9	0	0
+6.0 to +6.9	0	0

Giant Sunspots and Intense Solar Flares

Before considering the characteristic distributions of the small geomagnetic storms, it is of interest to compare, as in Figure 2, the distributions of the giant

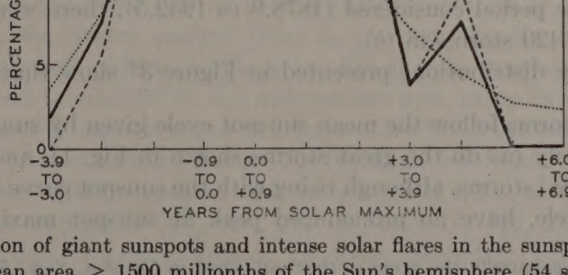

FIG. 2—Distribution of giant sunspots and intense solar flares in the sunspot cycle [full curve for sunspots of mean area $\geq$ 1500 millionths of the Sun's hemisphere (54 spots); dashed curve for intense solar flares of magnitude 3+ (55 flares); dotted curve for mean sunspot "numbers" (Zurich)]

sunspots and intense solar flares (magnitude 3+), both phenomena being closely associated with great geomagnetic storms.

Data for sunspots of mean area during disk passage $\geq$ 1500 millionths of the Sun's hemisphere have been abstracted from the *Greenwich Photoheliographic Results*. A list of solar flares of magnitude 3+ is published in *Monthly Notices*, **103**, 246, 1943, and is continued in *Septième Rapport de la Commission pour l'Étude des Relations entre les Phénomènes Solaires et Terrestres* (1951, p. 124).

As might be expected, there is good agreement between the distributions, with respect to the sunspot cycle, of the giant sunspots and of very intense solar flares.

The Small Geomagnetic Storms

A division of small storms into two categories, (*a*) those with sudden commencement (SC) and (*b*) those with indefinite onset (non-SC), was made for statistical purposes in a paper from Greenwich in 1928 [6]. It was concluded that "there seem to be grounds for suspecting that storms with SC's are more closely correlated with sunspots than those without."

In 1940, Bartels [7] put forward the suggestion of two types of solar corpuscular streams, "nascent" and "mature." Without definitely associating them with SC and non-SC storms, respectively, Bartels did postulate that the nascent streams proceeded from solar flares which, when intense enough and not too far from the central meridian, produced the great magnetic storms that almost invariably begin abruptly, if not with a large SC. The observed data of intense solar flares and great geomagnetic storms [8] support this hypothesis. In addition, Bartels identified the mature streams with sequence storms and their origin with hypothetical *M*-regions on the Sun.

For the purpose of studying the 27-day recurrence tendency, E. and O. Thellier in 1948 [9] used the above divisions of storms into SC and non-SC types. Quite independently, the phenomenon of recurrence was re-examined in a paper [10] from Greenwich. (These results will be referred to later.)

Distribution with Sunspot Cycle

With these preliminary remarks, we now give the distribution (averaged for seven sunspot cycles) of the small storms recorded at Greenwich-Abinger with respect to the maximum of each cycle in the same manner as for the data in Figures 1 and 2. Over the period considered (1878.9 to 1952.5), there were 235 storms in category (*a*) and 420 storms in (*b*).

The frequency distributions presented in Figure 3* show that

(1) The SC storms follow the mean sunspot cycle given by sunspot "numbers" quite closely (as do the great storms shown in Fig. 1); and
(2) The non-SC storms, although rising with the sunspot curve at the beginning of the cycle, have no pronounced peak at sunspot maximum, but after

*This Figure is essentially the same as that published in *Geophys. Sup.*, 5, 174, 1948, except that the data are now referred to the epoch of maximum instead of minimum, and the ordinates expressed in terms of percentage frequency.

two years from this epoch continue at a higher frequency level than the sunspots and SC storms until the final drop at minimum. It is these post-maximum storms, often showing 27-day recurrence, which are associated with disturbed ionospheric conditions, especially noticeable on radio

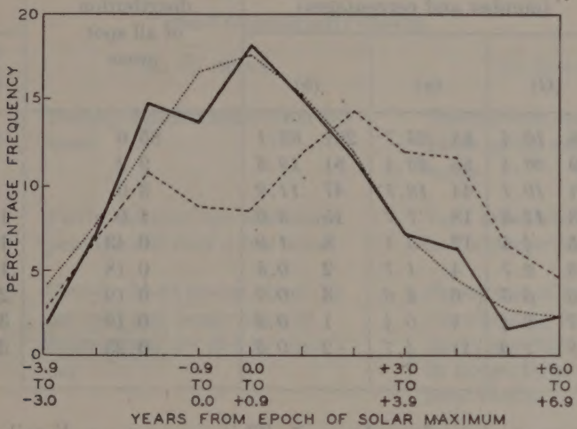

Fig. 3—Distribution of small magnetic storms in the sunspot cycle, 1878.9–1952.5 [full curve for SC storms (235 storms); dashed curve for non-SC storms (420 storms); dotted curve for mean sunspot "numbers" (Zurich)]

channels passing near the auroral zones at a time when quieter conditions might have been expected because of the decline of the sunspot cycle. These small storms are also closely associated with auroral glows or other minor forms of auroral activity seen from this country, as for instance in 1952 [11].

It is significant that this difference of frequency distribution within the sunspot cycle for (*a*) SC storms and (*b*) non-SC storms is combined with a statistical difference of association with sunspots, as suggested in 1928 (*loc. cit.*).

The progressive trend of association with sunspots for great storms (*G*), small SC storms (*a*), and small non-SC storms (*b*), respectively, is clearly seen in Table 2 that has been derived in the following manner.

Taking in turn the onset time of each geomagnetic storm in each of the above three categories, the largest sunspot (that is, the one with the largest mean area during its disk passage) within 4.0 days (= 53° of solar longitude) of the central meridian has been tabulated* in the appropriate area range in column 1 of the Table. The number of cases is given in column 2 for the great storms, in column 3 for the small SC storms, and in column 4 for the small non-SC storms. The numbers in italics are these values expressed as a percentage of the total number of storms in the respective categories (*G*), (*a*), and (*b*), namely, 110, 235, and 420. The average distribution in area groups of all spots (excluding 1-day spots) over a

*This information is given for the years 1874 to 1927 in *Greenwich Photoheliographic Results*, 1927, pp. 131-138.

Table 2

(1) Area range of sunspot	(2) Geomagnetic storms (number and percentages) (G)		(3) (a)		(4) (b)		(5) Mean percentage distribution of all spot areas	(6) Ratios (2)/(5)	(7) (3)/(5)	(8) (4)/(5)
0–250	18	*16.4*	84	*35.7*	261	*62.1*	85.6	0.2	0.4	0.7
250–500	29	*26.4*	55	*23.4*	81	*19.3*	9.2	2.9	2.5	2.1
500–750	21	*19.1*	44	*18.7*	47	*11.2*	3.0	6.4	6.2	3.7
750–1000	13	*11.8*	18	*7.7*	15	*3.6*	1.0	11.8	7.7	3.6
1000–1250	5	*4.5*	12	*5.1*	8	*1.9*	0.43	10	12	4
1250–1500	3	*2.7*	4	*1.7*	2	*0.5*	0.18	15	9	3
1500–1750	6	*5.5*	6	*2.6*	3	*0.7*	0.19	29	14	4
1750–2000	7	*6.4*	1	*0.4*	1	*0.2*	0.19	34	2	1
>2000	8	*7.3*	11	*4.7*	2	*0.5*	0.23	32	20	2

sunspot cycle is next given in column 5. This percentage distribution appears to be essentially similar from year to year.

The last three columns give for (*G*), (*a*), and (*b*), respectively, the ratio: distribution values for associated spots/mean or typical distribution values for all spots.

It will be seen that for (*G*) this ratio shows a marked increase (0.2 to 34) with increasing sunspot area. No further increase in the value occurs after the area group 1750-2000 millionths of the Sun's hemisphere; in point of fact, 9 out of the 14 greatest spots with area $\geq$ 2000 units had no associated great geomagnetic storm.

The rise in the ratio value for small SC storms (*a*) is also marked, but less so than for the great storms.

For small non-SC storms (*b*), no rise occurs, and the small and roughly constant value of 2 or 3 indicates an absence of correlation with sunspots.

A significant feature of this absence of association with sunspots is the large number of occasions (68) when no spots were present within the prescribed limits of $\pm$4.0 days from the central meridian. In 38 cases, the entire disk was spotless. For small SC storms, the number of spotless days was 8, and for great storms nil. This feature, suggesting an inverse correlation between small non-SC storms and sunspots, is at times quite striking for prolonged 27-day recurrence sequences as in 1951.

Thus, the broad division of the smaller storms into two categories, dependent on the occurrence of SC's, is supported both on the grounds of frequency distribution within the sunspot cycle and of a sunspot criterion prevailing at storm onset.

Since the allocation of the small storms depends solely on the presence or absence of an SC, we shall in conclusion review other characteristics of the two categories (*a*) and (*b*), firstly with respect to the storm traces themselves, and secondly with respect to the tendency for 27-day recurrence.

General Characteristics of Storms (a) and (b)

The following summary of characteristics for small storms (*a*) and (*b*) derived from an examination of Greenwich and Abinger magnetograms (supplemented by time-pattern diagrams) suggests that this general division is not wholly arbitrary.

Small Geomagnetic Storms

Characteristic	(*a*) *SC storms*	(*b*) *Non-SC storms*
Onset	Usually definite apart from SC itself	Indefinite in most cases, sometimes to the extent of several hours
Ending	Fairly definite, but sometimes petering out over a few hours	Very indefinite to the extent of half a day or more
Duration	Usually 24-36 hours; about 10 per cent last longer than 36 hours; some are shorter than a day	Sometimes of long duration, extending up to about a week; about one-third last longer than 36 hours; there are cases of short-lived storms
Trace character	Rapid or fairly rapid oscillations; occasionally the character changes to the type opposite	Slow oscillations, generally with phase differences between H and D; frequently there are peaks, pinnacles, or bays
Storm-time variation	Often apparent in H	Not apparent
27-day recurrence	Many of these storms are isolated (like the great storms) on a time-pattern diagram; nevertheless, short recurrence sequences do sometimes occur	Recurrence tendency definitely shown, especially by the long sequences towards sunspot minimum

Although prototypes of the above two classes (*a*) and (*b*) can be clearly discriminated, there is some merging of their respective characteristics, so that it is sometimes difficult to recognize a particular storm as belonging to one class rather than to the other.

An uncertainty in the correct allocation of a storm to (*a*) or (*b*) arises in the records around 08^h at Greenwich-Abinger when SC's tend to be suppressed (Geophys. Sup., 5, 166, 1948). In this connexion, any systematic effect in the data presented in Figures 3 and 4 would appear to be negligible. In any future work of this kind, however, the presence or absence of a SC must be settled in cases of any doubt by referring to magnetograms representing world-wide conditions, as was in fact done in the case of the present data from 1940 to 1952.

The 27-day Recurrence Tendency

The analysis carried out by E. and Mme. Thellier of the respective recurrence tendencies of (*a*) SC and (*b*) non-SC storms suggests a clear-cut distinction between the two storm categories. The non-SC storms show [12] recurrence peaks at $+27^d$

and -27^d, and with diminishing significance peaks at $+54^d$ and -54^d, and at $+81^d$ and -81^d. The SC storms show no significant recurrence peaks whatsoever.

This is a striking statistical result, but exceptions, more frequent than would appear from chance alone, do occur in the Greenwich list of storms, and those exceptions are reflected in the statement of characteristics given in the above Table.

The non-recurrence of all SC storms found by the Thelliers appears consistent with the previously recognized non-recurrence of "great" storms, which are essentially intense storms of SC or otherwise very abrupt onset. It will also be seen from the earlier Greenwich results [13] that for the more intense of the *small* storms (mean of H, D, and $Z \geq 180\gamma$) there is also no significant recurrence peak at $+27^d$, and furthermore that no peak at $+54^d$ appears until storms of mean range 150-179γ are reached. It was therefore concluded that the 27-day recurrence tendency is a feature mainly of the smallest storms.

There is here an apparent paradox in the statistical non-recurrence of great geomagnetic storms which deserves attention. The flare origin of corpuscular streams responsible for the more intense geomagnetic storms can hardly be doubted,

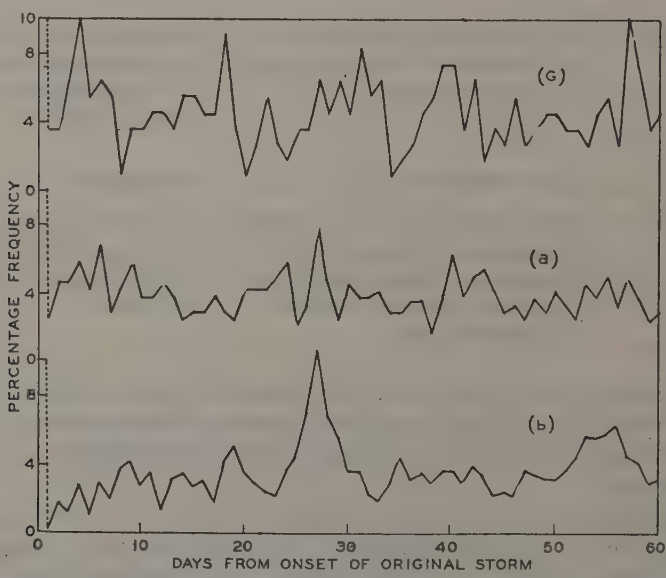

FIG. 4—Analysis of 27-day storm recurrence, 1874–1951 [(G) for great storms (110); (a) for small SC storms (240); (b) for small non-SC storms (414)]; primary peak at 0^d (dashed line) = 100 per cent

and such flares are highly, though not exclusively, related to the larger sunspots. The activity in such areas, effective from the terrestrial point of view when they are passing through the central half of the Sun's disk, is not infrequently continued intermittently to a second or even third disk passage.

A broad recurrence peak of geomagnetic activity might therefore be expected to show itself in a statistical analysis. In point of fact, if we take the largest sunspots,

that is, those with mean area during solar disk passage $\geq$ 1500 millionths of the Sun's hemisphere, such a 27-day recurrence pulse has been found [14], not apparently due to long-continued corpuscular streams, but to fresh streams originating from new flares in the immediate region of the recurrent sunspot.

Now, as already seen from Table 2, the small SC storms (like their great prototypes) are related statistically to sunspots—the incipient regions for flare occurrence and the ejection of corpuscular streams (nascent type) of limited duration. It is therefore somewhat surprising to find from the Thelliers' analysis no evidence of any 27-day recurrence of geomagnetic activity.

This statistical distinction between the respective recurrence tendencies of SC and non-SC storms is, however, confirmed by a superposed-epoch analysis of the Greenwich small storm data 1879-1952 using storm frequencies and not C magnetic character-figures. Thus, only one day, the day of onset, represents each storm, so that each integer in the analysis is independent of the adjacent integers. This is not so for the C values (as used in the Thelliers' analysis), because a storm may last for a few days. As against this advantage, the present analysis does not include any recurrent disturbance unless it is up to storm level.

The results of this analysis are displayed in Figure 4. Recurrence peaks around $+27^d$ and $+54^d$ are clearly shown for the non-SC storms (b), while they are entirely absent in the curve for the great storms (G). Of some doubt, however, are the data for SC storms (a). In this case, the significance of the apparent peak at $+27^d$ was determined by applying the "t-test" [15] to the ordinate values of Figure 4 (a), considered logarithmically.* It was found that the probability of occurrence of a value as high as that at $+27^d$ was about 0.02. Among 60 values, therefore, its presence must be regarded as being due to chance alone.

Summing up these remarks on the 27-day recurrence tendency, it may be fairly said that there is a clear statistical distinction between SC and non-SC storms. It should be pointed out, however, in the case of SC storms, whose correlation with sunspots has already been established (*vide* Table 2), that, as it is equally likely for a flare to occur in a given region on any one of the eight days within the statistical limits of -4^d to $+4^d$ from C.M.P. of the region, one would expect that any 27-day recurrence peak, if present at all, would be correspondingly broad. The difficulties of establishing the presence of a peak would be further increased if there were several flare-active spots in existence at the same time.

The marked 27-day recurrence tendency shown by the small non-SC storms supports the hypothesis of long-continued corpuscular streams (the "mature" streams according to Bartels), first suggested by Maunder half a century ago. The origin of these small non-SC storms is still perplexing, for although it seems probable that there is a basic connexion with coronal features (and with the long duration prominences), no statistical analysis to date has made the relationship conclusive [16].

Acknowledgment is gratefully made to the Astronomer Royal for permission to carry out this work.

We have also to thank Mr. H. F. Finch and Dr. P. A. Wayman for helpful discussion.

*Logarithmic values fit a normal distribution more closely than do the natural values.

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ROCK MAGNETISM AND THE EARTH'S MAGNETIC FIELD DURING PALEOZOIC TIME*

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ABSTRACT

A brief appraisal is given of the observations and arguments that are advanced in support of the opinion that during Paleozoic time the earth's magnetic field retained approximately its present orientation, and, except for possible brief excursions, its present sense.

Since 1945, continuous attention has been given to the subject of rock magnetism at the Department of Terrestrial Magnetism, Carnegie Institution of Washington. This program was initiated about 1935 and has been focused on the question, "To what extent is it possible to trace the history of the earth's magnetic field in geologic time by the study of the magnetic properties of rocks?". Results obtained up to 1949 have been reported in various papers. The present brief paper gives an abbreviated account of the results and conclusions reached during the past 3-1/2 years of almost uninterrupted work. It is our intention to publish the full details in the near future. During the course of this study, a number of individuals have participated: particularly grateful mention must be made of the contributions of O. W. Torreson and P. F. Michelsen, and of the helpful and stimulating criticism of M. A. Tuve and H. E. Tatel.

Simply stated, we think there is, in our data, a fair case for believing that since Cambrian time the earth's field has remained essentially in its present sense and roughly in its present orientation. The word "think" is used advisedly, for we do not have a proof that is certain, and the dikes, sills, and sediments having inverse magnetizations still are not completely understood. We are of the opinion, however, that anyone who concludes that the earth's field has reversed since Cambrian time is drawing a conclusion on questionable grounds.

As to the question of the degree of variability of the earth's total moment in past times, we as yet are not ready to say much. We have found a limited number of sediments having undetectable moments ($< 10^{-8}$ cgs/cc) and yet a respectable susceptibility, one that by comparison with other samples suggests that a reasonable residual moment should be present. Whether this property is an expression of a gradual demagnetization, or of unfavorable circumstances of deposition, or of a lack of the earth's field at the time of deposition, we do not know. As to the upper limit of intensity of the earth's field, we have in mind a promising method of approach which as yet we have examined in only a preliminary way. It depends

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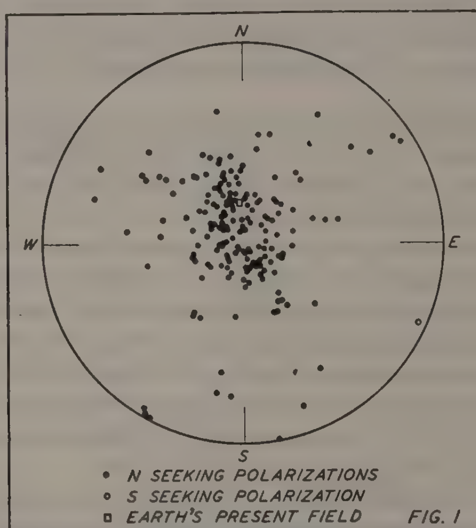
on the determination of the minimum steady magnetic field required to change the direction of magnetization of samples having polarizations that have been proved to have remained stable. The results should be valid for an upper limit if the ferromagnetic ingredient consists of a single magnetic phase with no memory and if the direction of magnetization is not controlled by grain shape anisotropy. We know that the latter is not the case in several instances from studies of directional susceptibility, but the samples used in the preliminary studies showed the behavior of a system consisting of more than one phase.

A summary plot (Fig. 1) shows all the directions of magnetization we have been able to measure in undeformed flat-lying Paleozoic sediments. These come from 14 exposures in the northeastern United States (see Fig. 2; not included in original



POLARIZATIONS OF FLAT-LYING PALEOZOIC SEDIMENTS

presentation). We estimate the probable experimental error of the plotted directions as not exceeding 10° in practically all cases; more than half the samples have sufficiently strong moments that the total probable error for them does not exceed 5°. In addition to these 182 measured samples, there were about 50 samples with moments too weak to measure. The exposures range in age from Ordovician through Permian, and somewhat more emphasis has been given the older sections. It is significant to note that all of these polarizations except one (open circle in Fig. 1) are north seeking downward. Likewise, it is significant that there is a preponderance of polarizations having high inclination. The distribution of polarizations by octants is: NE 23 per cent, SE 22 per cent, SW 18 per cent, and NW 37 per cent. This distribution does not change greatly when the coordinates are shifted so as to make one of the division planes pass through the present direction of the earth's field.

Faced with these observations, the question next arises whether the observed

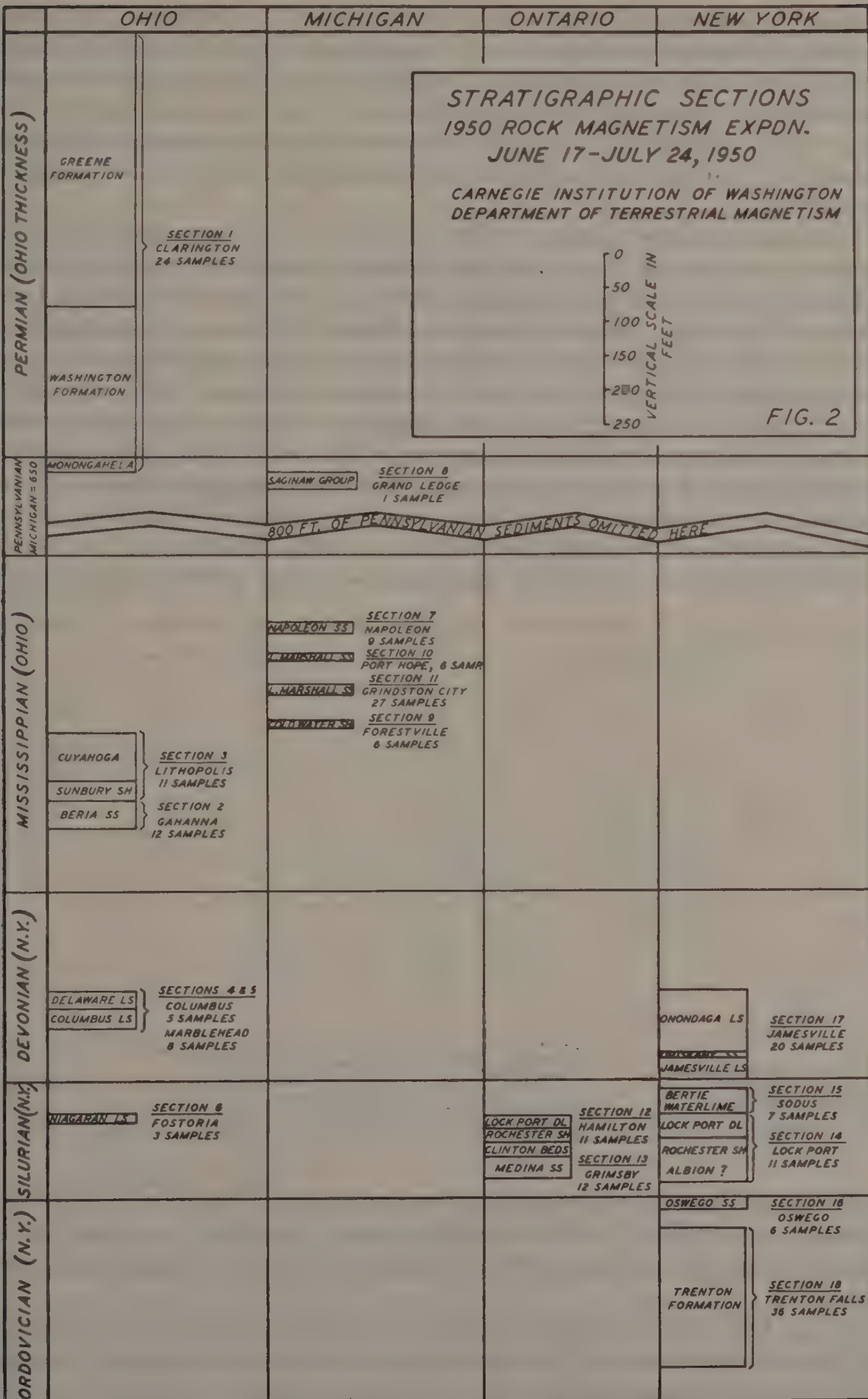

OHIO
MICHIGAN
ONTARIO
NEW YORK
STRATIGRAPHIC SECTIONS
1950 ROCK MAGNETISM EXPDN.
JUNE 17-JULY 24, 1950
CARNEGIE INSTITUTION OF WASHINGTON
DEPARTMENT OF TERRESTRIAL MAGNETISM
0
50
100
150
200
250
VERTICAL SCALE IN FEET
PERMIAN (OHIO THICKNESS)
GREENE FORMATION
WASHINGTON FORMATION
SECTION 1
CLARINGTON
24 SAMPLES
PENNSYLVANIAN MICHIGAN = 650
MONONGAHELA
SAGINAW GROUP
SECTION 8
GRAND LEDGE
1 SAMPLE
800 FT. OF PENNSYLVANIAN SEDIMENTS OMITTED HERE
MISSISSIPPIAN (OHIO)
NAPOLEON SS
SECTION 7
NAPOLEON
9 SAMPLES
SECTION 10
PORT HOPE, 6 SAMP.
L. MARSHALL SS
SECTION 11
GRINDSTON CITY
27 SAMPLES
SECTION 9
FORESTVILLE
6 SAMPLES
CUYAHOGA
SUNBURY SH
BERIA SS
SECTION 3
LITHOPOLIS
11 SAMPLES
SECTION 2
GAHANNA
12 SAMPLES
DEVONIAN (N.Y.)
DELAWARE LS
COLUMBUS LS
SECTIONS 4 & 5
COLUMBUS
5 SAMPLES
MARBLEHEAD
8 SAMPLES
ONONDAGA LS
JAMESVILLE LS
SECTION 17
JAMESVILLE
20 SAMPLES
SILURIAN (N.Y.)
NIAGARAN LS
SECTION 6
FOSTORIA
3 SAMPLES
LOCK PORT DL
ROCHESTER SH
CLINTON BEDS
MEDINA SS
SECTION 12
HAMILTON
11 SAMPLES
SECTION 13
GRIMSBY
12 SAMPLES
BERTIE WATERLIME
LOCK PORT DL
ROCHESTER SH
ALBION ?
SECTION 15
SODUS
7 SAMPLES
SECTION 14
LOCK PORT
11 SAMPLES
ORDOVICIAN (N.Y.)
OSWEGO SS
SECTION 16
OSWEGO
6 SAMPLES
TRENTON FORMATION
SECTION 18
TRENTON FALLS
35 SAMPLES

FIG. 2

directions of magnetization give a correct picture of the fields that prevailed at the time the samples were deposited. On two grounds, we must necessarily question each observed polarization: magnetic instability may allow the polarizations to turn gradually from some initial direction toward some averaged direction of the earth's field, and there may be mechanical deflections of the primary magnetization (distortion of the bed during drying and compaction, non-ideal settling of the particles, etc.).

In the matter of the magnetic stability of rocks, we can now make a number of statements: we can offer some excellent evidence that certain specific rocks have faithfully retained their magnetizations since at least late pre-Cambrian time; a number of Ordovician sediments from the Hudson Valley-Lake Champlain region have obviously had their primary magnetizations completely obliterated; we can show examples of late pre-Cambrian, Ordovician, Devonian, Mississippian, and Triassic rocks which clearly are neither completely stable nor unstable (example in Fig. 3). The tests of stability we have made by observing the present directions of magnetization in ancient conglomerates and distorted beds. Completely stable polarizations in conglomerates are observed today as vectors at random; partially stable polarizations are biased preferentially in some direction, and we consider that polarizations are completely unstable when, from pebble to pebble in the

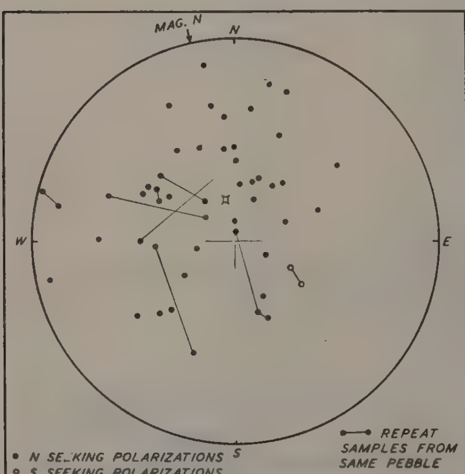


FIG. 3
UPPER TRIASSIC CONGLOMERATES, PORTLAND AND LAKE QUONNIPAUG, CONN.; SUFFERN, N.Y.

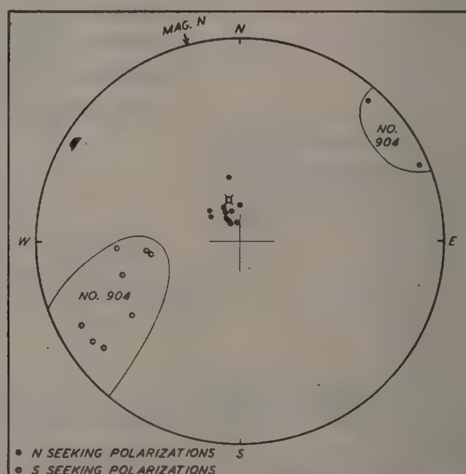


FIG. 4
CHAZY BRECCIA (ORDOVICIAN), REYNOLD'S POINT, ISLE LA MOTTE, VERMONT

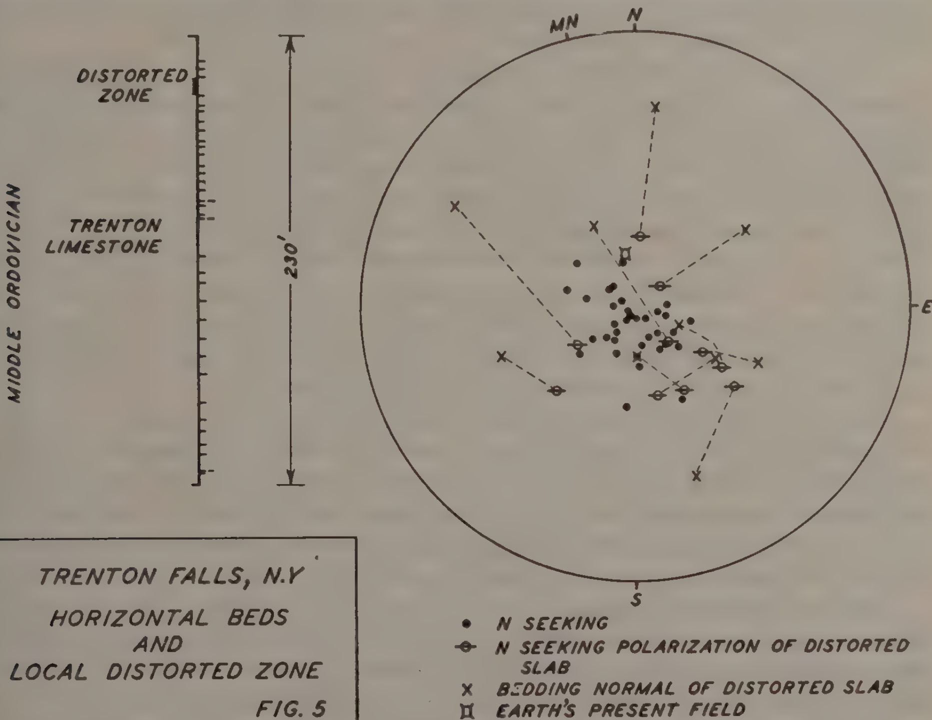
conglomerate, they are oriented in the same direction. This type of observation, of course, tells nothing directly about the cause of instability, nor about the conditions or time interval during which the polarizations went through their greatest change.

In one Ordovician conglomerate (Fig. 4), we have observed that all rocks do not have the same stability. Of 12 nearly-contiguous pebbles sampled, 11 had the same direction of magnetization within 10°. Ten cores from the twelfth pebble had magnetizations scattering ±30° from their average direction, and this average

direction differed from that of the other "pebbles" by 130°. Obviously, the material in this particular piece had a significantly greater degree of magnetic stability.

In our early limited experience, we found by this sort of testing that remarkable stability seemed to be the rule. You may imagine our initial disappointment when we first encountered the clearly unstable polarizations and the partially stable ones. But we now feel that even from these we can learn something of value concerning the history of the earth's field. The interesting point is that these unstabilized polarizations seem to be converging, roughly speaking, towards the direction and sense of the earth's field today. The more important fact is that, for many rocks, the "time constant" of this convergence is to be measured in some cases, at least, assuming steady rates, in terms as high as hundreds of millions of years. It was obvious at the start of the study that many magnetically unstable rocks must exist in nature; the task for us was to locate and identify at least a few with polarizations of significant stability.

An illustration of this important point that we can find examples of significant stability in the flat beds is provided by Figure 5. Here the clustering of polarizations



TRENTON FALLS, N.Y.
HORIZONTAL BEDS AND LOCAL DISTORTED ZONE
FIG. 5

of the horizontal undeformed beds is clear. Lying significantly outside this group are the polarizations observed in samples from the local distorted zone which is composed of the same material as the enclosing flat strata. We can here recognize samples with long time constants of stability, and we observe the steeply-inclined normal polarizations of the same material in the undisturbed condition.

As to the possible causes of instability, we can make several guesses. We know,

for example, that AC fields in the laboratory cause some samples to change polarizations rapidly, and we can wonder whether the various modulations of the earth's field spread out over long times can have the same effect. An intriguing notion is that in the equatorial regions where the earth's field has its smallest values and where high-latitude auroral disturbances are lacking, the rocks may show a greater degree of magnetic stability.

From observations in relatively young Triassic conglomerates (Fig. 3), we received the hint that heating may be of considerable importance in the matter of stability. Of course, to be dogmatic about the thermal history of any geologic section is risky, but clearly these Triassic samples had been appreciably heated by nearby intrusive diabase sills. Of the 50 samples measured, 48 are north seeking downward and scattered considerably in direction. We may wonder whether the completely unstabilized polarizations we found in the Ordovician of the Hudson Valley-Lake Champlain region are an indication of a more rugged thermal history than we at first believed, rather than a valid indication of the probable stability of sediments in general. We feel that, in comparison with all of these conglomerates, the flat-lying Paleozoic rocks probably have had milder thermal treatment, and hence it is reasonable that they may have more stable polarizations.

One other line of argument that strengthens the belief that the flat-lying Paleozoic sediments probably have a significant degree of magnetic stability is as follows: we have sampled a limited number of exposures of pre-Cambrian gneisses, diabases, and ore bodies, and to summarize the observations quickly, we will say that the observed residual magnetic moments are greatly scattered in direction—whether the sample-to-sample distance be on the scale of inches, feet, or miles. Certainly, we are dealing here with ferromagnetic material having a high degree of stability. It is presumably this same sort of material which is responsible for the magnetic moments of many of the sediments after it is ground to small size and redeposited. One would predict that, if anything, the finer grain size produced by erosion would lead to greater stability in the sediments.

We believe that in yet another way we can argue in favor of a significant degree of magnetic stability in the flat-lying Paleozoic sediments. Occasionally, we have encountered individual beds where in a matter of inches the directions of magnetization change as much as 150°. We have come into the habit of regarding these "wild" polarizations as stable ones which received their dispersion by mechanical disturbance taking place at the time of deposition or possibly shortly thereafter.

This interpretation, though reasonable, may not be justified, for we have no direct observational evidence under controlled conditions of the influence of grain size and shape, compaction, turbulent deposition, dessication, etc., on polarizations. Perhaps in this respect our studies are particularly lacking, for we undoubtedly are overly naive in assuming that at the time of deposition all the sediments we sample acquired a magnetization that reflects accurately the prevailing earth's field (neglecting stability considerations). That this assumption is inaccurate seems to be illustrated by the steady decrease of inclination with increase of age in the Pleistocene varved clays. It is only reasonable to expect that the same processes affected the Paleozoic sediments, but to what extent we do not know.

To review our stand on the flat-lying Paleozoic beds, we feel we can make a fair case for believing in a significant degree of magnetic stability among certain sediments, and yet we cast doubts on the hypothesis that at the time of deposition the sediments invariably acquire a valid primary magnetization that they retain without change in the face of the effects of compaction, distortion, diagenesis, etc. With what, then, are we left?

Taking as pessimistic a view as possible, I think the situation is no worse than the following: at the time of deposition and shortly thereafter, the sediments have polarizations that, for a guess, are rarely more than 90° from the prevailing direction of the earth's field. Some of these polarizations are stable, and many more have time constants of stability (under the conditions of thermal history prevailing in the flat beds) which our experiments show (by biased randomness in conglomerates) are to be reckoned in terms of tens and perhaps hundreds of millions of years. We observe that these polarizations today are almost exclusively north seeking downward, and that the preponderance of them is close to the direction of the earth's field today $\pm 30°$. The clustering thus represents a sort of averaging of whatever wandering the earth's field has undergone, plus additional scatter introduced by mechanical processes and varying time constants of stability. Because of the long time constant of stability for at least a few rocks which have been identified (in flat beds and conglomerates), we reach the conclusion that for the most part the earth's field has remained in about its present orientation and sense, on the average, to give the observed pattern of polarizations. The behavior of the unstable conglomerate pebbles is consistent with this conclusion. Very short term and infrequent reversals of the earth's field would not be revealed by this system.

A few words should now be added about the complex problem of appraising the significance of inverse polarizations. In the Appalachian Mountains, we have encountered a number of widely separated sections where many dozens of feet of Silurian strata with inverse magnetizations are interbedded with others of identical appearance having normal polarizations. Through these sections, there are a number of well-established faunal zones characterized by ostracods having a very restricted occurrence in the geologic time scale. Outside the deformed geosynclinal area, the flat-lying contemporaneous beds containing the same faunal assemblages have normal polarizations exclusively. Granting the stability of all these polarizations and taking them at their face value, these findings would seem to indicate that such reversals as the earth's field may have undergone in Silurian time took place over a relatively small area of the earth that was nevertheless still a large area when expressed in square miles; they took place very rapidly; they lasted for a short time; they took place without yielding transitional directions between the two senses; and, finally, they took place in a zone that later was destined to become first deeply buried by additional sedimentation and then later become folded and deformed during a mountain building orogeny. In view of the complexity of this problem, it seems well not to believe that these findings prove a reversal of the earth's field during Silurian time.

It seems to us wiser to attempt to understand these polarizations along the lines suggested by Néel's theoretical treatment, which offers various ways in which

reversals of the sense of magnetization may take place. Recent verification of some of this theory, at least, seems to be provided by Nagata's latest observations on the magnetization behavior of a Japanese inverse extrusive rock.

We are trying to get a better insight into this problem by studies of some excellent pre-Cambrian inverse diabase dikes in Michigan.* To date, we have established that they are uniformly magnetized to within at least 1/4″ of the contact, and that cooling the samples quickly in the earth's field from above the Curie point does not yield inverse magnetizations. We have started some annealing experiments, because we have found an isolated dike only two feet wide which has uniform inverse magnetizations. We would be quite excited if we should find that the two interacting phases called for by Néel's theory require more time to exsolve than is available in the usual rapid cooling during laboratory experiments. Predicting from this theory, one would say that the phases had sufficient opportunity to exsolve during the time of cooling of the two-foot dike.

To summarize, from a consideration of all of our observations, it is reasonable to believe that through most of Paleozoic time, except for possible brief excursions, the earth's magnetic field retained essentially its present orientation and sense. Our observations do not give adequate proof that this was so, but there are now enough facts known about inverse polarizations to make it reasonable to ask for detailed support of any proposal that they demonstrate reversals of the sense of the earth's field.

*Details have been published (J. Geophys. Res., 58, 243-260, 1953).

THE PERMANENT MAGNETISATION OF HORIZONTAL VOLCANIC SHEETS

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(Original manuscript received March 16, 1953, revised manuscript July 28, 1953)

ABSTRACT

The magnetisation of igneous rocks is often largely due to thermo-remanent components. Several horizontal sheets of acid tuffs in New Zealand exhibit similar magnetisation patterns. Each sheet has a basic minimum Q value; superimposed on this is an amplitude of polarisation pattern which, for one sheet examined in detail, is found to vary with depth in a similar manner to the inverse ratios of the computed cooling times over the temperature range $T_0 \rightarrow 0.75\ T_0$, T_0 being the instantaneous temperature of deposition of the lava.

INTRODUCTION

Igneous rocks, particularly extrusive varieties, often show a high permanent polarisation acquired by cooling through the temperature range between Curie point T_c and ambient temperature, in the geomagnetic field. The mode of development of this "thermo-remanent magnetisation" has been investigated chiefly by Nagata [see 1 of "References" at end of paper]. The physical mechanism responsible for it is not yet definitely known, though Néel [2] has evolved a theoretical explanation. Briefly, the characteristics of thermo-remanence are as follows:

(1) The rock, which can be considered as an ensemble of ferromagnetic grains set in a non-magnetic matrix, acquires on cooling in a magnetic field between any two temperatures T_2 and T_1 (where $T_c > T_2 > T_1$) a remanence $J_{2.1}$. The amplitude of J depends on the strength of the ambient field, the characteristics of the rock, and the temperature interval. On reheating to the higher temperature T_2, a similar amount of thermo-remanence $J_{2.1.}$ is destroyed.

(2) The sum of the partial polarisations acquired over any number of temperature intervals between T_c and ambient temperature T_a in a field H, is that acquired by cooling the rock in a field H from T_c to T_a.

(3) The magnetisation acquired has, in general, the same direction as the ambient field H. The thermo-remanent polarisation is often much greater than the induced magnetisation of the rock represented by the product of its susceptibility S and the strength of the geomagnetic field H. Qualitative observations by Chevallier [3], Nagata [1], and Robertson [4] have suggested that (a) the thermo-remanence of igneous bodies is greater near the edges than in the centre, and (b) the more glassy and basic the rock, that is, the greater the dissemination of the ferromagnetic mineral,

the greater is the thermo-remanence. The parameter $Q = J/SH$ has been devised by Koenigsberger [5] to express the thermo-remanence as a characteristic of the rock. Over a single geologic body, where the susceptibility of the ferromagnetic content is uniform, this represents a mass characteristic of the magnetic material. At small particle sizes, the susceptibility of magnetite decreases, introducing a second variable into the ratio. In the work to be described, the variation of Q across horizontal lava "flows" is described and an attempt is made to relate the values to a theoretical cooling-rate curve.

THE PATETERE IGNIMBRITES

The horizontal sheets investigated in the present study are located in the North Island of New Zealand (Fig. 1). The formation consists chiefly of a group of Plio-

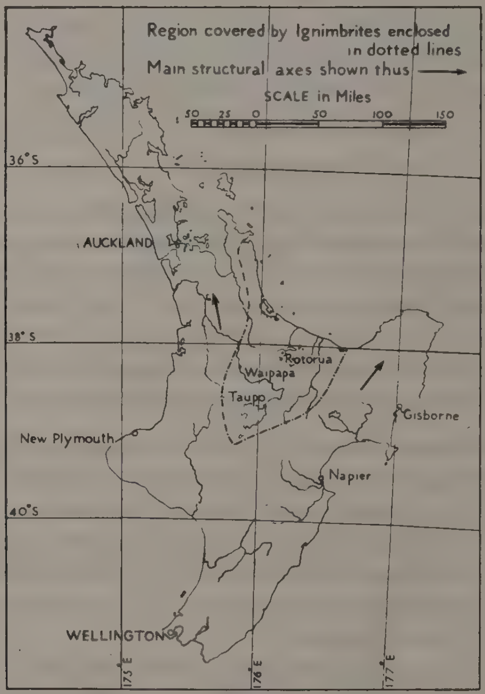

Fig. 1—Occurrence of Ignimbrite sheets in New Zealand

cene rhyolitic rocks having a peculiar constitution and named by Marshall [6] "ignimbrite." The nature of their efflux and transmission is not at all clear, for though the ignimbrites cover some thousands of square miles as horizontal sheets they are not related to any of the volcanic cones which constitute the most striking physiographic features of the North Island Volcanic Plateau. Widespread occurrence of horizontal single thin sheets, with little variation in thickness, requires a mobility not usually associated with acid flows.

Rivers have cut steep gorges through the ignimbrite sheets, and access roads to dam sites reach river level at several points. It is possible to obtain samples throughout a section of the sheets which, though not vertical, may be taken as such in view of the semi-infinite character of the sheets. Furthermore, at river level many boreholes have been drilled, allowing samples of the lowest ignimbrite sheets to be procured.

Conventionally, there are three sheets in the series considered, and it was originally thought that these corresponded to three eruptive phases. Of latter years, geologists have suggested that the sequence may be more complex, although it is difficult to separate more than three sheets on a hand specimen basis.

Initially, sampling took place at Waipapa, a dam site on the Waikato River. Oriented samples from the "upper" and "middle" sheets were obtained every 10 to 15 feet from exposures along the access road to river level (378 feet). Borehole cores were sampled for the "lower" sheet.

MEASUREMENT OF THE MAGNETIC PROPERTIES

The susceptibility and the strength and direction of the permanent polarisation of each sample were measured. For the purpose of the present study, only the first two quantities were required. The direction of the permanent magnetisation will be discussed in a later paper.

The susceptibility was measured by a bridge method. The inductance of a coil in one arm of an inductance bridge was altered by the insertion of a specimen, thus unbalancing the bridge. To rebalance, an adjustment was made to a variable inductance, calibrated in terms of susceptibility. The instrument was mains operated; it included a built-in oscillator operating at a frequency of 230 cps and an amplifier-detector with a visual-null indicator. The specimen of powdered rock was contained in a glass cylinder, $3\frac{1}{2}$ inches long and 1 inch in diameter. The test field was 1.57 gauss.

The permanent magnetisation of a 2-cm cube was measured by a dynamic method, similar to that described by Bruckshaw and Robertson [7]. The specimen was rotated about a vertical axis on the axis of a pair of back-to-back coils. The resulting signal was compared in amplitude and phase with that produced by a magnet of known moment rotating between a second pair of coils and geared to the same driving shaft as the rock specimen. The three mutually perpendicular components of polarisation were obtained by rotating around two axes of the specimen.

The ratio Q was calculated for each specimen, the strength of the geomagnetic field at the time of extrusion of the rock being taken as 0.5 gauss.

THE MAGNETISATION PATTERN OF THE WAIPAPA IGNIMBRITES

The Q factor for each of the samples is plotted in Figure 2 against a vertical scale of altitude. Geologically allotted boundaries of the three phases are shown. These boundaries are characterised by an increase in Q from above and below. It is reasonable to suppose that at other altitudes where such characteristics appear there are also sheet divisions. This increase in Q towards the boundaries of sheets is in agreement with the observations of Chevallier [3], who noted a

similar phenomenon in the flows of Mt. Etna, and Robertson [4], who measured the Q variation across some tholeiite dykes in northern England.

The common characteristics of the curves are twofold. There is a "basic" value of Q, different for different sheets, below which no values fall; and a superimposed variation towards the surfaces, the form of this being similar for each

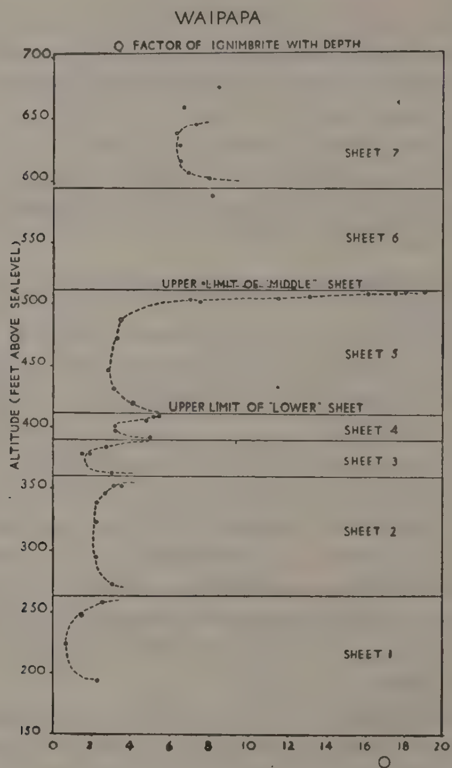

Fig. 2—Variation of Q with depth—Waipapa ignimbrite

sheet. The sheets are annotated by number from the bottom upwards for ease of reference. An inferred sheet, No. 6, was not sampled in the inner parts, because the road passed through alluvium between the altitudes constituting its probable boundaries. Sheet 5 was sampled intensively near its upper surface after one specimen was found to possess a Q of 18.

Cooling takes place by conduction and radiation, through the upper and lower surfaces of each sheet. The rate of cooling through any part of the temperature range $T_0 \rightarrow T_a$ has been determined at a number of points in the lava flow from theoretical considerations. Cooling rate determines many of the properties of the crystals in a flow, including particle size distribution, and, according to qualitative observations made by other authors, the greater the dissemination of the ferromagnetic minerals the larger the Q of the rock.

THE DECAY OF TEMPERATURE IN A LAVA FLOW

The loss of heat from a lava flow has been investigated, subject to several assumptions, by Boydell [8]. Though Boydell was primarily interested in the heat flow through the rock underlying the lava, the form in which he has developed the required Fourier equation is suitable for the study of the decay of temperature at points within the flow. Consider a semi-infinite horizontal sheet of thickness "l" cm deposited instantaneously at T_0°C on the ground rock. The diffusivity "h^2" of the rock and the lava are assumed identical and independent of temperature. The temperature of the ground rock is 0°C at time $t = 0$, and the upper surface of the flow is considered to be cooled to 0°C at the time $t \simeq 0$ and to be maintained at that temperature throughout the cooling, which takes place solely by conduction (Fig. 3).

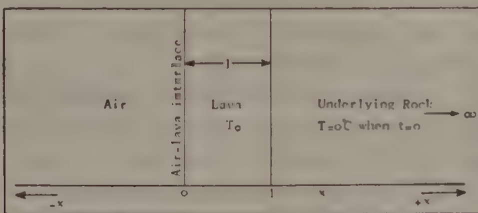

FIG. 3—Initial conditions on deposition of lava

Conditions governing the one-dimensional flow of heat in solid media are expressed by Fourier's abbreviated equation.

$$\frac{\delta T}{\delta t} = h^2 \frac{\delta^2 T}{\delta x^2} \qquad \text{.........................(1)}$$

Development of the solution of this equation subject to the conditions that

$$T = \mathrm{f}(x) = 0 \qquad \text{at } x = 0$$

$$\left.\begin{aligned} T &= \mathrm{f}(x) = T_0 \qquad \text{when } 0 < x < l \\ T &= \mathrm{f}(x) = 0 \qquad \text{when } l < x < \infty \end{aligned}\right\} \text{at } t = 0$$

has been found by Boydell to be

$$T = T_0\left[\frac{2}{\sqrt{\pi}}\int_0^q e^{-\beta^2}\cdot d\beta - \frac{1}{2}\left\{\frac{2}{\sqrt{\pi}}\int_0^{q\cdot l+x/x} e^{-\beta^2}\cdot d\beta - \frac{2}{\sqrt{\pi}}\int_0^{q\cdot l-x/x} e^{-\beta^2}\cdot d\beta\right\}\right]$$

where $q = x/2h\sqrt{t}$

Solution of this equation for values of depth x produces a family of curves of the change, with time, of the temperature at specific points within the flow. From these curves can be obtained the time taken by the rock at any point to cool through any part or the whole of the temperature interval $T_0 \rightarrow T_a$. The solution of Fourier's equation often demands excessively simplifying assumptions. The assumptions made in the present case are discussed separately below.

(*a*) *Uniformity of temperature of deposition*—In many ways, the ignimbrites are rocks which approach closely the ideal conditions for heat flow study. Sheets have horizontal upper and lower surfaces, such wide occurrence that they may be considered as infinite sheets for practical purposes, and in the light of all evidence they are thought to have been extremely mobile and of low viscosity.

(*b*) *The lava-air interface is always at 0°C*—This assumption is supported mainly by the qualitative observations of vulcanologists and others. Jagger [9] has asserted that it is possible to bear one's hand in contact with the surface of lava (pahoehoe) within an hour of its being emplaced. Perrett [10] has remarked that it was possible to enter the town of St. Pierre a few hours after the great nué of 1912 had passed through. On the other hand, a simple temperature distribution in a lava may be upset by the presence and effusion of large quantities of volatiles which may act as an efficient heat carrier. However, a compact form of rock develops quickly after the evolution of the volatiles. In effect, the upper surface is not at zero temperature, but at some value that decreases with time, and Berry [11] has estimated on a quantitative basis that a layer of approximately 5-cm thickness added on top of the lava would produce, at the real surface, a temperature condition approaching reality, provided that the new imaginary upper surface were maintained at 0°C. This thickness is independent of the depth of the lava base. However, it is impossible to make any quantitative allowance for the thin scoriaceous and vesicular layer which often exists on the surface of a lava flow. Such layers are noticeably absent from the ignimbrites. This is believed to be a feature of the method of deposition, for there are too few erosion features to suggest that a scoriaceous layer has been subsequently removed.

(*c*) *The thermal diffusivity "h^2" is the same for both lava and underlying rock at all temperatures*—As the lava and the underlying rock in the case considered here are so strongly related in their mineral and chemical characteristics, it is to be supposed that at any temperature their diffusivities are of the same order, but that variation in h^2 at any instant across a vertical section might occur due to the temperature gradient. The diffusivity h^2 is a function of the thermal conductivity K, the heat capacity per unit mass r, and the density d, and is expressed by the relation.

$$h^2 = \frac{K}{rd}$$

For uniform density, the variation of h^2 with temperature can be discussed by examining the variation with temperature of the conductivity K and the heat capacity r. The specific heat increases with temperature for almost all rocks until the values at 1,000°C are about 30 per cent higher than those at room temperature. The thermal conductivities, however, vary by no means uniformly. Up to 500°C, on the average, the conductivity may be said to increase by 10 per cent. Values at higher temperatures have not been recorded, but if further increase is assumed to be linear the joint effect of the variation of r and K with temperature is to reduce h^2 by about 10 per cent at 1,000°C. The value used, $h^2 = 0.0118 \text{ cm}^2 \text{ sec}^{-1}$ is that chosen by Boydell for rhyolite and andesitic flows. It corresponds well with values given in later geological literature [12].

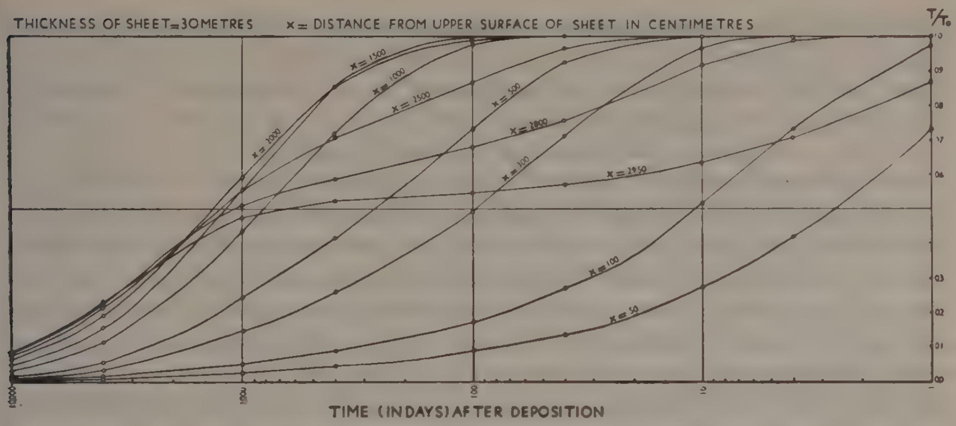

Fig. 4—Decay of temperature in lava sheet

The curves showing the decay of temperature in a sheet of thickness 30 metres and diffusivity $h^2 = 0.0118$ cm^2 sec^{-1} are reproduced in Figure 4. The temperatures at various depths x with time are given in terms of T_0. From these curves, the time taken at these points within the lava for the temperature to fall from T_0 to any other temperature can be determined. In Figure 5 are shown the inverse of the times taken to cool through the temperature intervals $T_0 \rightarrow 0.9T_0$, $T_0 \rightarrow 0.75T_0$, and $0.6T_0 \rightarrow 0.3T_0$. The curve of Q values within the limits of experimental error

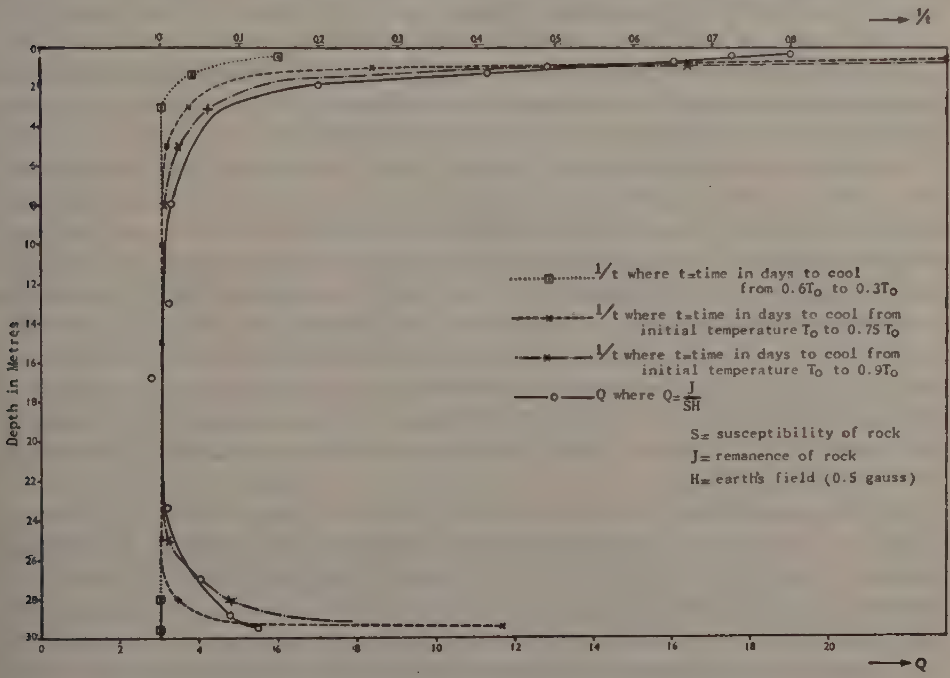

Fig. 5—Q factor compared with rates of cooling in a lava flow 30 metres thick

is similar to the curves of the first two temperature intervals, but not in the lower half, to the interval $0.6T_0 \rightarrow 0.3T_0$, which for most lavas is approximately the range in which the majority of the thermo-remanence is acquired. This lack of dependence of the amplitude of thermo-remanence on the rate of cooling below Curie point has been verified experimentally by Nagata [1].

The cooling curve and Q curve have three main characteristics. Near the upper surface, both decrease very quickly, until they stabilise at about $5 \rightarrow 6$ metres depth. For the middle 60 per cent of the sheet, both Q and inverse cooling times hardly vary, Q being at its minimum "basic" value for the sheets. Five metres from the bottom of the sheet, Q and cooling rate begin to increase and Q does not in this case achieve values as high as near the upper surface, though because of the nature of the exposure sampling is not so reliable as near the upper surface. However, the indication is that variations of Q and cooling rate occur at similar depths in the flow. The temperature range through which cooling rate is critical could best be determined by a study of a suitable lower contact, for the cooling rate curve at points near the lower contact is sensibly dependent on the range chosen. Near the upper surface, the cooling rate curve is similar in form for all temperature intervals.

EFFECT OF REHEATING BY SUBSEQUENT FLOWS

When a lava is deposited on an older flow, considerable reheating of the older flow occurs. Theoretically, if the flows have identical thermal properties, the maximum temperature to which the surface of the older flow is reheated is equal to $T_0/2$, T_0 being the instantaneous temperature of deposition of the upper flow. A value for T_0 of 960°C is preferred by Marshall [13] for the ignimbrites. The upper parts of the lower flow are thus reheated to within 100°C of the Curie point of magnetite. As sheet 5 has obviously been reheated, the effect of the reheating and subsequent cooling upon the final Q must be debated.

According to the experiments of Nagata [1] and Thellier [14], it can be proposed that if the thermo-remanence of the older rock is $J_{Tc,0}.\vec{H}_1$ ($J_{Tc,0}$ being the magnetisation per unit volume of rock acquired in unit field between Curie point and ambient temperature, and $\vec{H}_1$ being the geomagnetic field at the time of extrusion), then upon reheating to a temperature T in a field $\vec{H}_2$, an amount $J_{T,0}\vec{H}_1$ of thermo-remanence is destroyed and is replaced by the amount $J_{T,0}\vec{H}_2$. This assumes (*a*) that the thermo-remanence of the rock is independent of the act of reheating, and (*b*) that the thermo-remanent characteristics are independent of the rate of cooling. If $\vec{H}_1 \simeq \vec{H}_2$, then the thermo-remanence of a lava remains unaffected by the deposition of a later flow only if these two conditions are satisfied. The assumptions are discussed below.

(*a*) In some studies, to attempt to determine the temperature T for the ignimbrite sheets, 20 samples were reheated 12 times to successively higher temperatures from 100° to 600°C. After each heating, they were cooled to room temperature in a null field. Finally, they were allowed to cool in the geomagnetic field from 600°C to ambient temperature. The mean remanence developed was 1.10 times the original remanence (highest value 1.2, lowest 1.05). Such a small

increment in the thermo-remanence may be due to a higher ambient field during the laboratory experiment than obtained on deposition, or perhaps the original remanence had decayed slightly with time. It does not necessarily require any alteration in the properties of the ferromagnetic material of the rock. The susceptibility of the rock was unaltered by this thermal treatment.

(*b*) Nagata [1] has investigated the dependence of thermo-remanence on cooling rate below Curie point, within limits realisable in the laboratory. Varying the cooling times produced no effect on the thermo-remanence. It must be admitted, however, that the cooling rate in a flow is so slow that it cannot readily be introduced into laboratory experiments.

Two other points are of interest in this connection. The lower surface of the lower sheet would hardly be affected by the reheating by the upper sheet, yet the properties of samples from the lower parts of the lower sheet are similar to those of the upper part of the sheet upon reheating and cooling in the laboratory. Also, magnetisation curves of the sheet 5 ignimbrite show that the rock acquires over 80 per cent of its thermo-remanence in the temperature interval between Curie point (575°C ± 10°C) and 500°C. The majority of the thermo-remanence retained on the initial cooling is thus not destroyed on subsequent heating, unless changes occur in the ferromagnetic mineral which affect the thermo-remanent characteristics of the rock. This appears unlikely from (*a*) above.

CONCLUSION

The variation of thermo-remanence with position in a horizontal volcanic sheet may be the result of the variation of some crystal property with cooling rate. Néel's premise in a theoretical discussion of thermo-remanence [2], of the existence of single unique domain particles of a very low limiting size, suggests one variation, namely, the fluctuation of the particle size spectrum. Other properties of a sub-crystalline character are, no doubt, affected by cooling rate, but these the author is not competent to discuss.

ACKNOWLEDGMENT

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WINDS AT ALTITUDES UP TO 80 KILOMETERS*

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ABSTRACT

Wind data have been collected at altitudes between 30 and 80 km in the course of six rocket flights at White Sands Proving Ground during 1950 and 1951. Additional wind data to altitudes as high as 40 km have been obtained since 1948 by tracking radiosondes carried aloft by special high-altitude balloons launched at Belmar, New Jersey. Day-to-day wind changes at 30 km are discussed. From the mean wind structure, inferences are drawn as to upper atmosphere temperatures at higher latitudes.

During the past five years, considerable effort has been expended at the Signal Corps Engineering Laboratories in an attempt to learn more about winds and temperatures in the upper atmosphere, with special emphasis on the region between 30 and 80 km. Both balloon-borne equipment and rocket-borne equipment have been used for this purpose. The maximum altitude reached by the balloons has been slightly more than 40 km; this ceiling may be lifted to 50 km in the near future when larger balloons, now being developed, are available.

Rockets have been used to make measurements over the entire altitude range from 30 to 80 km. This has been accomplished by loading a number of special grenades in the nose of the rocket in such a way that, after the rocket reached 30 km, the grenades were ejected along the trajectory at intervals of about 6 km. Since these experiments were carried out at night, the position of each exploding grenade could be accurately determined by photographic triangulation. The time of each explosion and the time the sound waves reached the ground were accurately measured. From these data, it was possible to determine the velocity of sound, and thus the mean temperature, of each of the various atmospheric layers between grenades. This was the original purpose of this experiment and, indeed, temperature data have been obtained in this way for altitudes between 30 and 80 km [see 1 of "References" at end of paper].

It was found, however, that wind information could also be obtained if the angles of arrival of the sound waves at the ground were measured. How this was accomplished can best be understood by considering a simple analogy. If a stone is dropped near one shore of a pond of water, the normal to the wave front of the ripples that reach the opposite shore will point back to the stone. However, if the stone is dropped instead into a stream of water, the normal to the wave front striking the opposite shore will point not to the stone but to a virtual source which

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is downstream from the real source by a distance which depends on the velocity of the stream and the time required for the ripple to cross the stream. Similarly, if the air between an exploding grenade and the ground were motionless, the angle of arrival at the ground of the sound waves (after correcting for temperature refraction) should be the same as the angle of arrival of the light from the burst. However, if there is a discrepancy between the acoustical and optical angles, it is presumably due to motion of the medium and mean values of the magnitude and direction of this motion can be computed.

A total of 12 rocket-grenade experiments have been carried out during the past four years, but due to the time required to evaluate data, final results are available only from the first six experiments. Wind values from these experiments are shown in Figure 1. In the summer season, the winds are predominantly from

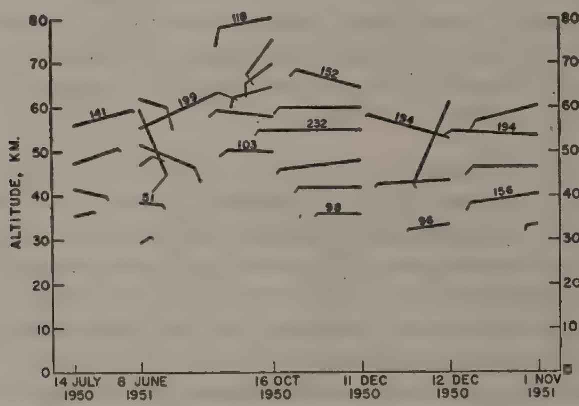

FIG. 1—Rocket-measured winds at altitudes between 30 and 80 km, represented as vectors; numbers indicate wind speeds in miles per hour; the length of the barb is a measure of the probable error

the east—in the winter season, from the west. The highest wind speeds are found at about 53 km, which is about 5 km above the level of maximum temperatures. In winter, mean winds at this altitude are about 200 miles per hour, compared with 150 miles per hour in summer.

The wind measurements which have been made with balloons are considerably more extensive than the rocket-measured winds, although they do not reach to nearly as high altitudes. These measurements have been made by using automatic direction-finding equipment to track a radiosonde transmitter carried aloft by an unusually large balloon. The results obtained from flights made at Belmar, New Jersey, during the past five years are shown in Figure 2. Instead of representing the winds at various altitudes by vectors, the mean values of the E-W and N-S components are shown. It can be seen that the mean circulation is essentially zonal, since the mean N-S components are negligible at all times. Between 0 and 20 km, the winds are westerly all year around. Above 20 km, the winds are westerly during the winter and easterly during the summer. This is in agreement with the observations of others [2]. The E-W components of the rocket-measured winds

are included in Figure 2 for comparison purposes. In the winter season, the agreement between balloon-measured and rocket-measured winds is quite good, in spite of the difference in the latitudes at which the measurements were made. In the summer season, the rocket-measured winds appear to be considerably stronger than the balloon-measured winds. This discrepancy is more apparent

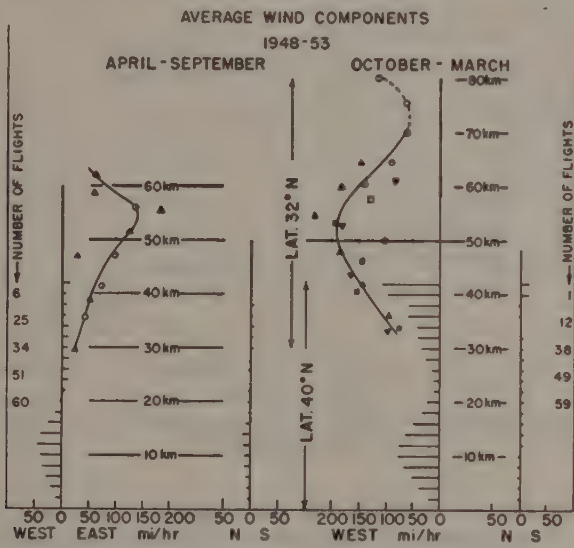

FIG. 2—Mean values of E-W and N-S wind components, for summer and for winter seasons, obtained from balloon flights made at Belmar, N.J., during the period 1948–53; the E-W components of the rocket-measured winds shown in Figure 1 are reproduced here for comparison purposes

than real, because the balloon-measured mean wind includes several flights in April in which the winds at these altitudes were westerly and rather strong, thus greatly reducing the magnitude of the mean easterly component. It is probably safe to say that the balloon-measured mean is representative of the mean wind over the whole period from April through September, while the rocket-measured mean is representative of the winds during June and July.

Although the mean flow at the higher altitudes is essentially zonal, the day-to-day flow occasionally shows pronounced meridional components. This is shown in the upper part of Figure 3, which is a vector plot of the winds at 30 km over Belmar, New Jersey, during January, April, and July 1953. The winds during the period 2-11 January 1953 are particularly interesting, because during this period the temperature at 30 km rose 20 degrees or so above normal, as is shown in the lower part of Figure 3. The mean temperature at this altitude and time of year is −50°C to −55°C. On 4 January 1953, the temperature was near the mean. However, on 5 January it rose to −45°C, and on 6 January to −35°C. There was no evidence of a subsequent temperature rise at lower altitudes, as had been observed by Scherhag [3]. A study of the index of geomagnetic activity during this interval revealed that there was an increase in the International Character Figure from

0.3 on 4 January to 1.7 on 5 January. The significance of this is not obvious, because an increase of 1.3 units on 24 December 1952 was associated with no pronounced temperature changes at 30 km. It is possible that the temperature rise was simply a consequence of advection of warm air from the south [4].

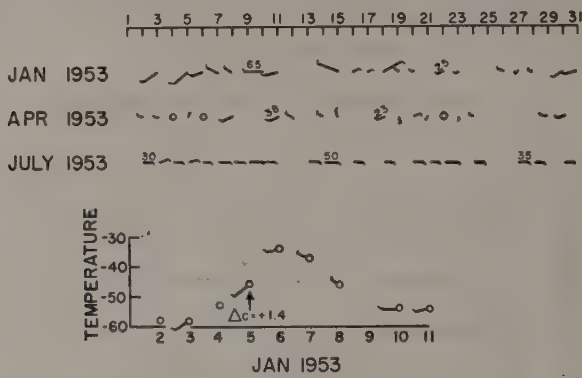

Fig. 3—(*Upper*) Winds at an altitude of 30 km over Belmar, N.J.; indicated winds speeds are in miles per hour

(*Lower*) Temperatures at the 30-km level over Belmar, N.J., during the period 2–11 January 1953

Information on the variation of the mean zonal winds with altitude, taken from Figure 2, is summarized in chart form in Figure 4, in order that inferences may be drawn as to the poleward temperature gradient required to account for these winds. Two interesting conclusions may be drawn from Figure 4, which

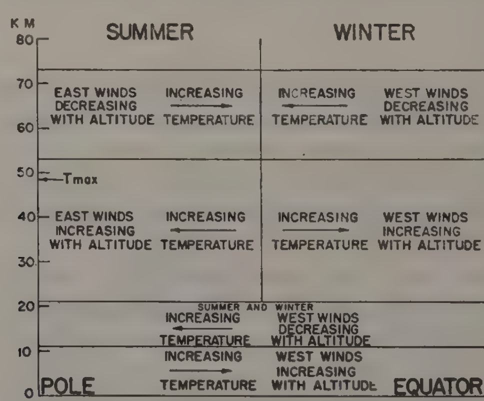

Fig. 4—Variation with altitude of the mean zonal winds and the poleward temperature gradient

should be valid at least for regions between 30° north and 40° north latitude. First, the variation of temperature with latitude should be least at altitudes of 53 km and 73 km. Second, if it is assumed that, at altitudes between 30 and 80 km, there is little or no seasonal temperature variation at latitude 30° north—and measurements at White Sands Proving Ground seem to indicate that this is

the case [5]—then it follows that there must be a pronounced seasonal change in temperature at higher latitudes. Thus, at altitudes between 20 and 53 km, summer temperatures must be appreciably higher than winter temperatures. However, between 53 and 73 km at higher latitudes, just the reverse is true—winter temperatures must be appreciably higher than summer temperatures. An explanation of this unusual temperature variation is undoubtedly to be sought in the seasonal variation in the ozone concentration at these altitudes.

Acknowledgments—The results presented in this paper are the consequence of the cooperative effort of many individuals, not only in the Signal Corps Engineering Laboratories, but in other government agencies. A complete list of all who contributed to the rocket-grenade experiment will be published elsewhere [1]. Special mention should be made of the assistance of Mr. A. G. Weisner, who computed the wind values shown in Figure 1, and of Mr. W. C. Conover and Mrs. C. J. Wentzien, who were instrumental in the collection and reduction of balloon-measured wind data.

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THE SPORADIC *E* LAYER AT KODAIKANAL

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ABSTRACT

An examination of the ionospheric records at Kodaikanal, which is located almost on the geomagnetic equator, reveals that the sporadic *E* layer here has some regular features not observed at other latitudes. It occurs in nearly 93 per cent of the half-hourly records during the daytime. Two main types of *Es* are observed; namely, (1) the patchy type with a well-marked diurnal variation, and (2) the blanketing type which occurs mostly during afternoons. It is found that neither meteoric activity nor thunderstorm activity has any appreciable influence on the formation of either of the two types of *Es*. No correlation is observed between *Es* and the geomagnetic field.

Introduction

Regular ionospheric observations with a multifrequency panoramic recorder were commenced early in 1952 at the Kodaikanal Observatory, which is located almost on the geomagnetic equator. The equipment used is the type C-3 automatic recorder, designed by the National Bureau of Standards, Washington, D.C. The frequency range of 1.0 to 25.0 Mc/sec is swept in an interval of 30 seconds, and records are obtained every half-hour from about sunrise to sunset. The ionospheric records here reveal that the occurrence of the "sporadic *E* layer" during the daytime is so regular that it may be regarded as a normal layer for this location. The characteristics of this *Es* layer are found to be such that neither meteoric activity nor thunderstorm activity can adequately account for its formation. There is also no correlation between *Es* activity and the geomagnetic field, and thus the problem is posed as to why the *Es* at this locality is so different from that observed at higher latitudes.

Frequency of occurrence

The most notable feature of the sporadic *E* layer at Kodaikanal is the high frequency of its occurrence during the daytime. In striking contrast with what has been observed at moderate and high latitudes, this layer is almost always present during the day. Among a total of 5,785 half-hourly records obtained during a year, covering the period $08^h\ 00^m$ to $16^h\ 00^m$ IST, *Es* occurred in no less than 5,372, or about 93 per cent of the total number. The percentage frequency of occasions when *Es* was observable during each of the 12 months of the year

under study is shown in Table 1. The occurrence is relatively rarer during the winter months.

Table 1—*Percentage frequency of occurrence of Es in half-hourly records from* $08^h\ 00^m$ *to* $16^h\ 00^m$ *IST*

Month	Percentage frequency of occurrence
1952	
June	95
July	92
August	96
September	94
October	94
November	92
December	87
1953	
January	81
February	95
March	95
April	97
May	96

The two main types of Es

The sporadic E layer at Kodaikanal can be classified into two main types. The first one, more frequently and regularly observed than the other, is of the patchy type exhibiting well-spread echoes. The reflections are only partial and

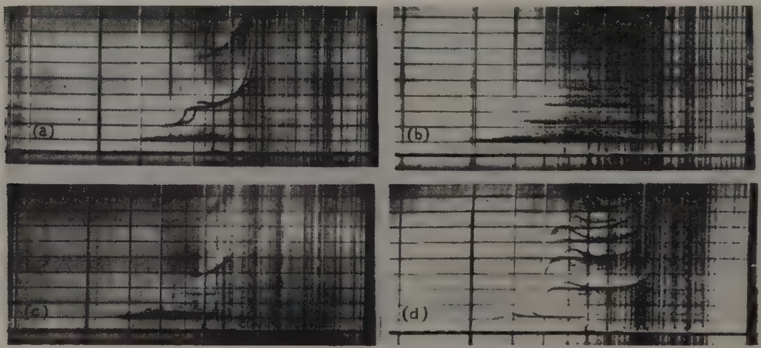

Plate I—Types of *Es* observed at Kodaikanal

hence the higher $F1$ and $F2$ regions are not occulted. This type of *Es* is shown in Plate I(a). The other type of *Es* is the blanketing type, illustrated in Plate I(b). It usually blankets the $F1$ layer, the critical frequency of which is in the range 4.0 to 4.6 Mc, but on other occasions blankets the $F1$ and $F2$ layers completely.

The first type of Es

A conspicuous feature of this type of *Es* is its diurnal variation. It forms about one to two hours after ground sunrise, and its critical frequency, *fEs* (the highest frequency for which reflections are observable), which is low in the morning, increases rapidly as the zenith angle of the sun decreases. The maximum *fEs* is reached by about noon, after which *fEs* decreases until evening, when this type of *Es* disappears. The layer forms in the morning *in situ* at the almost invariable height of 100 km, this height remaining unchanged during the day. It blankets the normal *E* layer for most of the time and, on some occasions, it is seen as a continuation of the normal *E* layer. Due to the regular occurrence of this *Es*, the normal *E* layer can seldom be perceived in the ionospheric records and consequently the characteristics of the normal *E* layer cannot be studied.

The plots of the hourly median values of *fEs* for daytime are shown in Figure

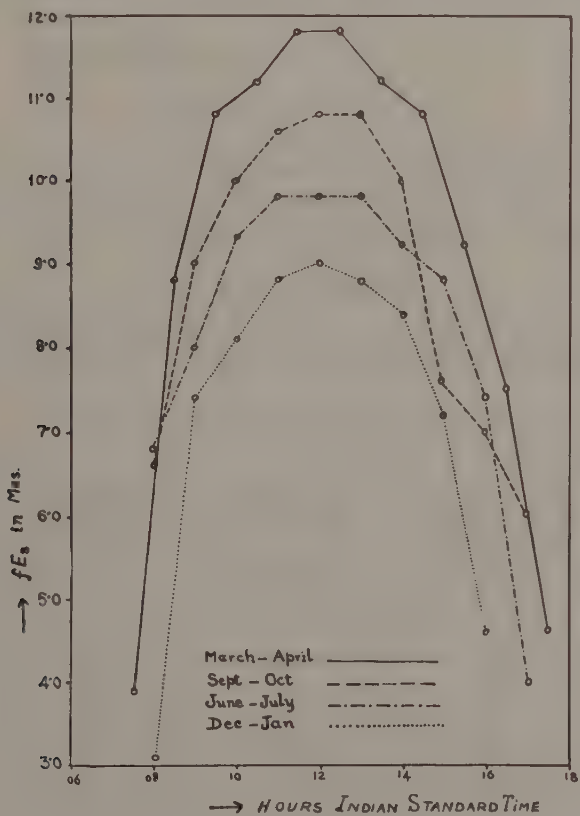

FIG. 1—Diurnal variation of *fEs* at Kodaikanal

1 for four periods of the year, representing the two equinoxes and the two solstices; namely, (*a*) March-April, (*b*) June-July, (*c*) September-October, and (*d*) December-January. All the four curves illustrate a well-marked diurnal variation of *fEs*. It is also seen that the midday ionisation of the *Es* layer as indicated by *fEs*

has an annual variation with a maximum near spring equinox and a minimum near the winter solstice. A secondary maximum occurs near the autumn equinox and a secondary minimum near the summer solstice. Figure 2 shows the variation of monthly median values of noon *fEs* during the year. These diurnal and seasonal

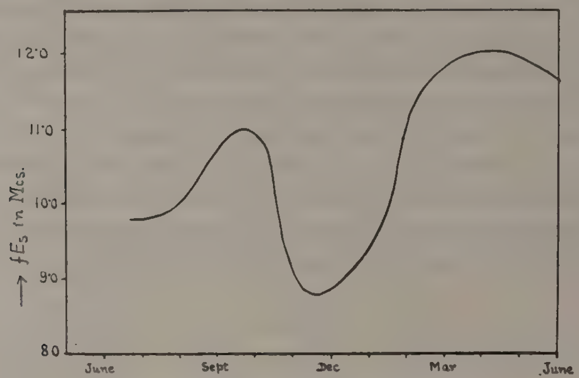

FIG. 2—Annual variation of noon *fEs*

variations of *fEs* apparently indicate some sort of solar control of the *Es* layer. This type of *Es* seems to resemble the constant-height type of *Es* observed at Brisbane by McNicol and Gipps [see 1 of "References" at end of paper].

The second type of Es

This blanketing type of *Es* occurs mostly during the afternoon hours. The duration of blanketing ranges from a few minutes to several hours. This type

TABLE 2—*Statistical data for blanketing type of Es*

Month (1)	No. days when blanketing type *Es* was observed (2)	No. half-hourly records (08^h-16^h) when blanketing was observed		No. occasions under col. 3 when there was complete blanketing
		08^h-$11^h.30$	12^h-16^h	
1952				
June	21	8	55	8
July	12	2	28	4
August	14	11	42	5
September	12	0	18	0
October	7	0	13	1
November	12	1	12	0
December	7	1	14	0
1953				
January	10	2	19	5
February	12	0	21	1
March	9	1	19	0
April	12	0	24	1
May	18	5	38	3

forms at a slightly greater height than the first type, and has a structure more continuous and better defined than the first. A notable feature is its high reflectivity, as shown by the occurrence of a number of multiple echoes. The penetration frequency varies widely from 6.0 Mc to 24.0 Mc, but the most frequent range is from 10.0 to 15.0 Mc. Table 2 gives some statistical data about this type of *Es* for the period of one year. Its occurrence seems to be truly sporadic in nature and its formation is due to some different cause. On some occasions, both the types of *Es* coexist, the blanketing one being higher, as shown in Plate I(*c*).

In addition to the two main types described above, there is a third type, which occurs rarely. This *Es* is sharply defined, with a complete absence of spread echoes, and is characterised by the presence of both ordinary and extraordinary components at the low-frequency end. Plate I(*d*) shows such a type of *Es* and is similar to Plate 7 of the atlas of ionospheric records published by the National Bureau of Standards, Washington, D.C. This unusual type of *Es* also blankets the *F*1 and *F*2 layers partially.

The origin of Es

The existence of more than one type of *Es* has been observed at other places also, and it would appear that more than one agency might be responsible for the formation of *Es*. Baral [2], in a recent study, has observed that meteoric impacts might be the main source of ionisation of the *Es* layer. The characteristics of the *Es* at Kodaikanal, however, do not lend much support to this view. In the first place, the diurnal variation of the first type of *Es* shows a pronounced midday maximum, whereas meteoric activity should be a maximum in the early hours of morning. During early morning, the occurrence of *Es* has been found to be very rare. Secondly, the blanketing type of *Es* occurs much more frequently during the latter half of the day than in the first. To study whether increased meteoric activity has any effect on *Es* ionisation, the ionospheric records during the periods of activity of the meteoric showers like the Leonids, Geminids, etc., during 1952-53, were examined. No perceptible change, either in the frequency of occurrence of *Es* or in the critical frequency of *Es*, was observed during those periods. During the periods of activity of Delta Aquarids, Perseids, Orionids, Leonids, and the Geminids of 1952, ionospheric records were available for the predawn period also (from $05^{h}\ 00^{m}$ IST) when meteoric activity may be expected to be even greater than during the daytime. These records also did not indicate any abnormal *Es* activity.

McNish [3] has found after simultaneous observations of meteor reflections obtained on both the ionosphere recorder and the meteor equipment that the meteor reflections are sharper and of much shorter duration than the typical sporadic *E* reflections seen in the ionospheric records. Also he did not find any correlation between the blanketing type of *Es* and meteoric activity. This experimental evidence supports the view that meteoric ionisation may only be short-lived. The correlation reported by other investigators [4] is probably between occurrence of this type of short-lived echoes and meteoric activity. At any rate, there appears to be no connection between either of the two types of *Es* observed at Kodaikanal and meteoric activity.

Es and thunderstorm activity

Following the hypothesis of C. T. R. Wilson that thunderstorms could cause an enhancement of the ionisation of the E region, Bhar and Syam [5] carried out an investigation to study this effect at Calcutta. Their results showed a statistical correlation between the frequency of occurrence of Es and the incidence of thunderstorms. However, Best, Farmer, and Ratcliffe [6], after a study of the effects of thunderstorm on the abnormal ionisation of the E region in southeast England, did not find any such correlation. Recently, Chatterjee [7] has found that the reflection coefficient of the sporadic E layer at Calcutta increases during a thunderstorm. The high frequency of occurrence of thunderstorms at Kodaikanal during the summer months was availed of by the author to study this effect. During the months of April and May 1953, thunderstorms occurred at Kodaikanal during the afternoon or early evening on 32 days. There was no appreciable change in the frequency of occurrence of Es on those days as compared with days without

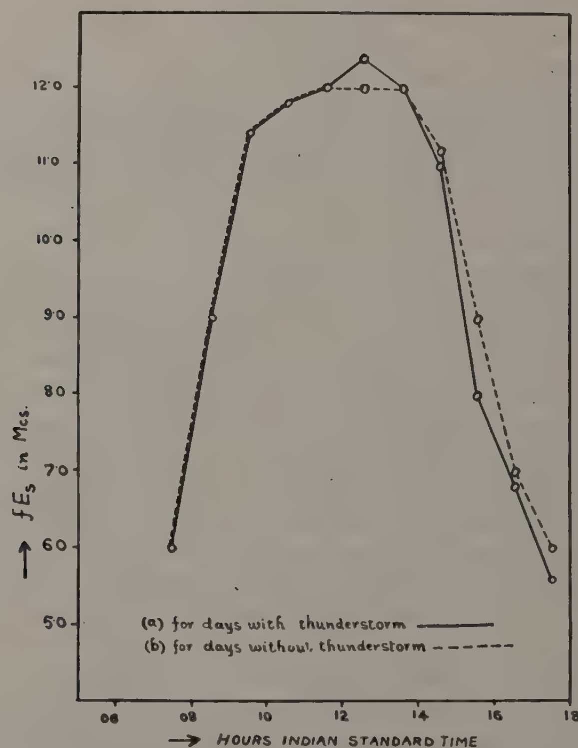

Fig. 3—Median hourly values of fEs

thunderstorm. The hourly median values of fEs (both the types of Es being taken into account) for thunderstorm days were plotted and compared with similar curves for days without thunderstorm. As shown by Figure 3, the two curves are almost similar. It is thus found that no perceptible increase of ionisation takes place on thunderstorm days. A similar result was obtained also for other

months having fewer days of thunderstorm. Besides this statistical test, a few individual cases were found in which there was no *Es* layer at all in the ionospheric records when a well-developed thunderstorm was occurring at the station. Also, an examination of the occasions of intense blanketing type of *Es* did not reveal any correlation with thunderstorms. The conclusion, therefore, is drawn that, so far as Kodaikanal observations show, thunderstorms do not exert any appreciable influence on the ionisation of the *Es* layer.

Es and the geomagnetic field

The high frequency of occurrence of *Es* during the daytime at Kodaikanal and the diurnal variation of *fEs* appear to be very similar to those at Huancayo, which is also located on the geomagnetic equator. This similarity fits in with the suggestion of Baral [2] and Sadami Matsushita [8] that a narrow zone of intense *Es* might exist over the geomagnetic equator. Both these investigators have also suggested that this narrow zone of intense *Es* may have some relationship with the intense eastward current (electrojet) over the geomagnetic equator. However, if this current-system were to have a control over the formation of the *Es* layer, one ought to find some correlation between the occurrence of intense *Es* and the magnetic elements. Preliminary examination has revealed no such correlation at Kodaikanal. Accumulation of more comprehensive data on *Es* near the geomagnetic equator may help to throw further light on this question.

The origin of the *Es* region thus remains to be explained. Cosmic radiation is capable of producing ionisation in the *E* region. Hulbert [9] showed that the ionisation produced by cosmic radiation in the whole of the ionosphere is much less than that produced by solar ultraviolet radiation. Using recent values for the intensity of primary cosmic radiation and by assuming that the energy lost through absorption is entirely utilised in ionising the air molecules, a rough calculation was made to obtain the extent of ionisation. The effects of secondary radiation, which introduce complexities, have been ignored. It was found that the number of ion pairs formed at the 100-km level may be of the order of 10^4 per cc. This value of ion density is much smaller than that determined from observed values of critical frequencies of the *Es* layer; namely, 10^6 to 10^7 per cc. It would appear that cosmic radiation by itself may not be sufficient to account for the ionisation of the *Es* layer. However, the effect of cosmic radiation on the ionisation of the *E* layer seems to be worthy of further examination.

The marked diurnal variation and the seasonal variation of *fEs* at Kodaikanal suggest the possibility that solar radiation might be an important factor controlling the formation of *Es* of the first type. McNicol and Gipps [1], who found a correlation between one of the types of *Es* at Brisbane and the amount of solar radiation, have put forth a suggestion that this *Es* might be formed due to the ionisation of preexcited atoms by the radiations in the visible part of the solar spectrum. If this view is correct, the process of the formation of the *Es* layer by solar action should be a very complex one, requiring detailed investigation. Why the occurrence of daytime *Es* is so regular at Kodaikanal (and perhaps at places very near the geomagnetic equator) and not so at other places where the solar radiation may be equally effective, will have to be accounted for.

The height of the sporadic E layer of the first type at Kodaikanal is more or less constant at 100 km. Whenever the normal E layer is also present, the two layers are seen at this height as a fairly continuous trace, with no well-marked critical frequency for the E layer. This suggests the possibility that the sporadic E echoes of the first type at Kodaikanal might be due to a redistribution of ionisation within the E layer itself, by some unknown process.

I wish to thank Dr. A. K. Das for his interest in this work and helpful criticisms.

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THE CONNECTION BETWEEN LUNAR HEIGHT CHANGES AND LUNAR CURRENTS IN THE *E*-LAYER*

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ABSTRACT

The height changes produced by vertical electronic diffusion in the presence of negative ions are examined in some detail. Application of the results to the *E*-layer shows that a previous qualitative discussion remains valid.

INTRODUCTION

Kinetic theory of an ionized gas in a magnetic field, **H**, directly connects the diffusion currents of the charge-bearing particles to the electric current,[1] **j**. The electron diffusion current, $y_2\mathbf{v}_2$, causes vertical motions of the ionosphere layers. In this way, observed lunar height changes in the *E*-layer have been compared to changes which a current system, derived from lunar variations in the earth's magnetic field, might be expected to produce. Also in this way, M. Hirono[2] estimated height changes from a current system which he obtained by an application of the dynamo theory.

The present paper examines more closely the height changes produced by vertical electronic diffusion. In I, the equation

$$F_2(z, y_2) = q(z) - r(y_2) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

governed the electron density in the absence of diffusion, where q was the electron production rate and r the recombination rate. In the presence of diffusion, Eq. (1) became

$$F_2(z, \bar{y}_2) = \mathrm{d}(\bar{y}_2 v_{2z})/\mathrm{d}z \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

If the effect of the right side in Eq. (2) be small, the solution may be written

$$\bar{y}_2 = y_2 + \delta y_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

with

$$\delta y_2 = \mathrm{d}(y_2 v_{2z})/\mathrm{d}z \div \partial F_2/\partial y_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

*This work supported by the U.S. Atomic Energy Commission.

[1] M. H. Johnson, J. Geophys. Res., 57, 405 (1952). The notation of this paper, hereafter designated I, will be followed throughout. Eq. (5*a*) of this paper should read $K_0 = -\lambda_2(\lambda_1 + \lambda_2)^{-1}$.

[2] M. Hirono, J. Geomag. Geoelectr., 5, 22 (1953).

At any given height, the change in electron density, δy_2, is equivalent to a change in height, δh,

$$\delta h = -\delta y_2 \div dy_2/dz \qquad (5)$$

$$= -d(y_2 v_{2z})/dz \div (\partial F_2/\partial y_2)(dy_2/dz) \qquad (5a)$$

According to Eq. (1), $(\partial F_2/\partial y_2)(dy_2/dz) = -(dr/dy_2)(dy_2/dz) = dq/dz$, which is the previous result. It is valid provided r depends on z only through y_2, whereas Eq. (5) remains valid even though r depends explicitly on z.

GENERAL FORMULAS FOR HEIGHT CHANGES

When negative ions of density, y_3, are included, equations having the form

$$F_1(z, y_1, y_2, y_3) = 0 \qquad (6a)$$

$$F_2(z, y_1, y_2, y_3) = 0 \qquad (6b)$$

$$y_1 = y_2 + y_3 \qquad (6c)$$

govern the equilibrium densities in the absence of diffusion. Eq. (6a) balances the creation and destruction of positive ions and Eq. (6b) balances the creation and destruction of free electrons. The condition of electrical neutrality, Eq. (6c), requires that the balance of negative ions be the dependent relation $F_1 - F_2 = 0$. In the presence of diffusion, Eq. (6) becomes

$$F_1(z, \bar{y}_1, \bar{y}_2, \bar{y}_3) = d(\bar{y}_1 v_{1z})/dz \qquad (7a)$$

$$F_2(z, \bar{y}_1, \bar{y}_2, \bar{y}_3) = d(\bar{y}_2 v_{2z})/dz \qquad (7b)$$

$$\bar{y}_1 = \bar{y}_2 + \bar{y}_3 \qquad (7c)$$

If the effect of the right side of Eq. (7) be small, the solution may be written

$$\bar{y}_1 = y_1 + \delta y_1 \qquad (8a)$$

$$\bar{y}_2 = y_2 + \delta y_2 \qquad (8b)$$

$$\bar{y}_3 = y_3 + \delta y_3 \qquad (8c)$$

where δy_1, δy_2, and δy_3 satisfy the equations

$$(\partial F_1/\partial y_1)\delta y_1 + (\partial F_1/\partial y_2)\delta y_2 + (\partial F_1/\partial y_3)\delta y_3 = d(y_1 v_{1z})/dz \qquad (9a)$$

$$(\partial F_2/\partial y_1)\delta y_1 + (\partial F_2/\partial y_2)\delta y_2 + (\partial F_2/\partial y_3)\delta y_3 = d(y_2 v_{2z})/dz \qquad (9b)$$

$$\delta y_1 = \delta y_2 + \delta y_3 \qquad (9c)$$

Eliminating δy_1 and δy_3,

$$\delta y_2 = [R_2 d(y_1 v_{1z})/dz - R_1 d(y_2 v_{2z})/dz][R_2 S_1 - R_1 S_2]^{-1} \qquad (10a)$$

with

$$R_1 = \partial F_1/\partial y_1 + \partial F_1/\partial y_3 \quad \ldots\ldots(10b)$$

$$R_2 = \partial F_2/\partial y_1 + \partial F_2/\partial y_3 \quad \ldots\ldots(10c)$$

$$S_1 = \partial F_1/\partial y_1 + \partial F_1/\partial y_2 \quad \ldots\ldots(10d)$$

$$S_2 = \partial F_2/\partial y_1 + \partial F_2/\partial y_2 \quad \ldots\ldots(10e)$$

Eq. (5) may be used to convert δy_2 into an equivalent height change.

The positive ion current, $y_1\mathbf{v}_1$, is easily expressed in terms of $\mathbf{j}$ and $y_2\mathbf{v}_2$. Addition of the three equations for the motion of the charged particles [Eqs. (1*a*), (1*b*), and (1*c*) of I] gives

$$\mathbf{j} \times \mathbf{n} = \lambda_1^{-1}(ey_1\mathbf{v}_1 + ey_3\mathbf{v}_3) + \lambda_2^{-1}ey_2\mathbf{v}_2 \quad \ldots\ldots(11)$$

Since $\mathbf{j} = e(y_1\mathbf{v}_1 - y_2\mathbf{v}_2 - y_3\mathbf{v}_3)$,

$$2ey_1\mathbf{v}_1 = \mathbf{j} + \lambda_1\mathbf{j} \times \mathbf{n} + (\lambda_2 - \lambda_1)\lambda_2^{-1}ey_2\mathbf{v}_2 \quad \ldots\ldots(12)$$

Substitution of Eq. (12) into Eqs. (10) and (5) gives

$$\left.\begin{aligned} \delta h = & -(\mathrm{d}y_2/\mathrm{d}z)^{-1}\{[(\lambda_2 - \lambda_1)(2\lambda_2)^{-1}R_2 - R_1]\mathrm{d}(y_2v_2)_z/\mathrm{d}z \\ & + (2e)^{-1}R_2\mathrm{d}(\lambda_1 j \times n)_z/\mathrm{d}z\}[R_2S_1 - R_1S_2]^{-1} \end{aligned}\right\} \quad \ldots\ldots(13)$$

It is also interesting to consider the change in electron density at a fixed altitude brought about by a change, δI, in the photoionization rate. Eq. (9) then determines δy_2 if the right sides of Eqs. (9*a*) and (9*b*) be replaced by $-\delta I$. Hence

$$(\delta y_2/\delta I)_z = -(R_2 - R_1)(R_2S_1 - R_1S_2)^{-1} \quad \ldots\ldots(14)$$

and Eq. (13) may be written

$$\left.\begin{aligned} \delta h = & (\delta y_2/\delta I)_z(\mathrm{d}y_2/\mathrm{d}z)^{-1}(R_2 - R_1)^{-1} \\ & \times \{[(\lambda_2 - \lambda_1)(2\lambda_2)^{-1}R_2 - R_1[\mathrm{d}(y_2v_{2z})/\mathrm{d}z + (2e)^{-1}R_2\mathrm{d}(\lambda_1\mathbf{j} \times \mathbf{n})_z/\mathrm{d}z\} \end{aligned}\right\} \quad \ldots(15)$$

CHARGE REACTIONS IN THE *E*-LAYER

To evaluate the partial derivatives in Eqs. (14) and (15), suppose that[3]

$$F_1 = I - \alpha_e y_1 y_2 - \alpha_i y_1 y_3 \quad \ldots\ldots(16a)$$

$$F_2 = I + (\rho + \chi n_a)y_3 - \eta m_b y_2 - \alpha_e y_1 y_2 \quad \ldots\ldots(16b)$$

where I is the photoionization rate of neutral molecules, α_e the coefficient for recombination of ions with electrons, α_i the coefficient for recombination of positive ions with negative ions, ρ the coefficient for photodetachment of electrons from negative ions, χ the coefficient for detachment of electrons by collision of negative

[3]D. R. Bates and H. S. W. Massey, J. Atmos. Terr. Phys., 2, 1 (1952), discuss in detail the numerical values of the rate coefficients in Eq. (16).

ions with molecules of type a, and η the coefficient for attachment of electrons to molecules of type b.

Eqs. (6) and (16) are sometimes written

$$q = (\lambda + 1)^{-1} I = (\alpha_e + \lambda\alpha_i) y_2^2 = \alpha_{eff} y_2^2 \quad \text{(17a)}$$

$$\lambda = y_3/y_2 = \eta n_b [\rho + \chi n_a + (\lambda + 1)\alpha_i y_2]^{-1} \quad \text{(17b)}$$

Eq. (17a) defines the effective electron production rate, q, and the effective recombination coefficient, α_{eff} .

With Eq. (16), the quantities R and S become

$$R_1 = -[\alpha_e + (2\lambda + 1)\alpha_i] y_2 \quad \text{(18a)}$$

$$R_2 = \rho + \chi n_a - \alpha_e y_2 \quad \text{(18b)}$$

$$S_1 = -[(\lambda + 2)\alpha_e + \lambda\alpha_i] y_2 \quad \text{(18c)}$$

$$S_2 = -[\eta n_b + (\lambda + 2)\alpha_e y_2] \quad \text{(18d)}$$

Substitution of Eq. (18) into Eq. (14) gives

$$\left.\begin{aligned} (\delta y_2/\delta I)_z = {} & (\lambda + 1)^{-1}[\rho + \chi n_a + (2\lambda + 1)\alpha_i y_2] \\ & \times \{2(\rho + \chi n_a)\alpha_{eff} y_2 - \alpha_i y_2[(3\lambda + 2)\alpha_e + \lambda(2\lambda + 1)\alpha_i] y_2\}^{-1} \end{aligned}\right\} \quad \text{(19)}$$

ELECTRON DENSITY CHANGES IN THE E-LAYER

On the assumption that the detachment rate, $\rho + \chi n_a$, is large compared to any of the recombination rates, which is probably true in the E-layer,[3] Eq. (19) simplifies to

$$(\delta y_2/\delta I)_z = [2(\lambda + 1)\alpha_{eff} y_2]^{-1} = y_2(2I)^{-1} \quad \text{(20)}$$

This result could be obtained directly from Eq. (17) for, if $\rho + \chi n_a \gg (\lambda + 1)\alpha_i y_2$, λ does not depend on y_2 and may be treated as a constant in the variation of Eq. (17a).

In principle, Eq. (20) could be tested by observing the changes in ionization that result from changes in the angle, θ, between the inclination of the sun and the vertical. In a homogeneous atmosphere, monochromatic radiation ionizes molecules at a rate proportional to $n \exp [-n(n_0 \cos \theta)^{-1}]$, where n_0 is the gas density at the point of maximum ionization for the sun directly overhead. Then

$$\delta I/I = -(n/n_0) \sin \theta (\cos^2 \theta)^{-1} \delta\theta \quad \text{(21)}$$

As n/n_0 could be estimated at the point of observation by comparing y_2 at this point to the maximum value of y_2 , $\delta I/I$ could be computed by Eq. (21). For a given $\delta\theta$, δy_2 could then be obtained from observation and the two sides of the equality $\delta I/I = 2\delta y_2/y_2$ compared. According to Eq. (19), $2\delta y_2/y_2$ should be larger than $\delta I/I$ by an amount that depends on the ratio of recombination rates to detachment rates; the equality holds when the ratio is zero. In practice, it would

be difficult to eliminate from the observations of δy_2 the density changes produced by diffusion. Perhaps averaging observations at short times before and after the overhead passage of a current focus would cancel out the diffusion effects well enough.

In the case of rapid detachment, Eqs. (20) and (18) substituted into Eq. (15) give

$$\delta h = y_2(2I\mathrm{d}y_2/\mathrm{d}z)^{-1}\tfrac{1}{2}\mathrm{d}[y_2v_{2z} + e^{-1}\lambda_1(\mathbf{j} \times \mathbf{n})_z]/\mathrm{d}z \qquad (22)$$

where use has been made of the fact $\lambda_2/\lambda_1 \sim 10^3 \gg 1$. As $100/H_0$ cm^{-4}sec^{-1} is an approximate numerical value for $y_2(2I\ \mathrm{d}y_2/\mathrm{d}z)^{-1}$, the comparison of Eq. (22) with Eqs. (9) and (4) of I shows that the modification of Eq. (9) consists in multiplying the term containing the axial diffusion factor, K_a, by 1/2 and the term containing the transverse diffusion factor, K_t, by $1/2(1 + \lambda_1/K_t)$. The numerical values estimated for δh ought to be lowered, perhaps, by a factor of 2. The qualitative discussion remains unchanged.

We summarize the previous discussion. We can understand the phase of lunar height changes at Canberra if $\mathbf{j}$ decreases with altitude faster than the gas density, for then the layer moves downward when the diffusion current is upward. We can understand other peculiarities in phase if axial diffusion plays a part, because this term which depends on $\mathbf{j}\cdot\mathbf{n}$ becomes large when the transverse diffusion, which depends on $\mathbf{j} \times \mathbf{n}$, becomes small. The first condition is plausible and the second possible only if the negative ion to electron ratio is about one, or larger.

Should λ_1 in fact, be much less than one in the E-layer, the lunar height changes must reflect the value of $\mathrm{d}(\lambda_1\mathbf{j} \times \mathbf{n})_z/\mathrm{d}z$ at the point of observation. The differentiated quantity is essentially the product of the current perpendicular to the magnetic field and the molecular density. The lunar wind system above Canberra would have to produce a current at the point of observation opposite in direction and nearly equal in magnitude to the main lunar system current which must flow at some other altitude in the ionosphere. Similarly, in England, the current at the point of observation could not be part of the main lunar current.

Very valuable information could be obtained from lunar height changes at the magnetic equator. The changes ought to be large.[2] Moreover, the horizontal east-west currents which are driven solely by the polarization electric field must be in the same direction at all altitudes and, indeed, rocket measurements of the magnetic field[4] indicate a current system of the expected direction and magnitude in the E-layer. Should the lunar height changes here appear out of phase with the current, there would be no alternative to a current density that decreases more rapidly with altitude than the gas density and, by inference, to a negative ion to electron ratio of the order of one, or larger. Should the height changes appear in phase with the current, the presumption would be very strong that at other latitudes, where the phase of lunar height changes disagrees with the phase derived from the main lunar current system, the currents at the point of observation are not part of the main lunar current system.

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THE ZENITH-ANGLE VARIATION OF COSMIC-RAY MESON INTENSITY*

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ABSTRACT

The observed $\cos^k$ zenith-angle variation of μ-meson intensity at low elevations is derived on the basis of a p^{-n} meson momentum spectrum at production. It is found that $k = n - 1$ to a good approximation, in agreement with experimental evidence. The region of validity of this relationship is discussed.

The variation of the directional intensity of cosmic-ray μ-mesons with zenith-angle ζ is well known, the counting rate at low altitudes being proportional to $\cos^k \zeta$, $k \sim 2$. It is of interest to consider the origin of this dependence and its bearing on other cosmic-ray phenomena.

From sea-level to mountain elevations, the hard (that is, penetrating) cosmic radiation consists primarily of μ-mesons resulting from the decay of π-mesons, which themselves originate in high-energy nuclear interactions at the top of the atmosphere. These mesons do not compose all of the hard components, however, with a definite proportion of protons present whose number decreases rapidly with increasing energy [see 1 of "References" at end of paper]. A contribution by locally produced mesons is also possible, although probably quite small. The experimental arrangements for zenith-angle variation measurements usually involve a counter telescope, with sufficient absorber above or between the counters to stop the soft component and with side counters in anticoincidence to prevent the recording of showers. More elaborate determinations have been performed [2], using delayed coincidence techniques in which the unambiguous detection of μ-mesons is possible, and it is the interpretation of these latter experiments that will be discussed here.

It is convenient to make use of the usual assumptions that the bulk of π-meson production occurs in a sufficiently restricted region near the top of the atmosphere so that at low elevations it may be considered as occurring in a single layer at a constant altitude, that the π-mesons are produced isotropically, and that their lifetime may be neglected in comparison with the μ-lifetime. According to Sands [3], the first approximation is satisfactory at low elevations for mesons of energy $\geq \sim 3mc^2$, a condition satisfied in zenith-angle measurements employing the usual 10 cm or more of Pb absorber. μ-decay in terms of the distance z from the point of production is given by

$$-\mathrm{d}N(z)/\mathrm{d}z = N(z)/\overline{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

*Assisted by the joint program of the U.S. Office of Naval Research and the U.S. Atomic Energy Commission.

where $\bar{R} = \tau p/m$ is the mean range of a meson corresponding to its lifetime τ, with p and m the meson momentum at elevation z and μ-meson rest mass, respectively. Integrating,

$$N(z)_p = N(0)_p \exp(-mz/\tau p)$$

for a given p. A meson incident at an angle ζ with the vertical has $z = h \sec \zeta$, h being the height of the production layer, and so

$$N(\zeta)_p = N(0)_p \exp(-mh \sec \zeta/\tau p) \quad \text{(2)}$$

To find the total variation of N with ζ, it is necessary to integrate over the meson momentum spectrum $F(p)\, dp$. Taking $F(p)\, dp = Ap^{-n}\, dp$, where n is about 3, and absorbing the constant A in $N(0)$,

$$N(\zeta) = N(0) \int_{p_{min}}^{\infty} p^{-n} \exp(-mh \sec \zeta/\tau p)\, dp \quad \text{(3)}$$

with p_{min} the minimum momentum required to penetrate the atmosphere and the experimental apparatus and, of course, varying somewhat with ζ. For an approximate result, p_{min} can be taken as 0, giving

$$N(\zeta)_{approx} = N(0)\Gamma(n-1)(mh \sec \zeta/\tau)^{1-n}$$

or

$$N(\zeta)_{approx} = N'(0) \cos^{n-1} \zeta \quad \text{(4)}$$

Hence this approximation gives for the variation a form identical with experimental findings. For a $\cos^2 \zeta$ distribution, a p^{-3} production spectrum is implied, which is in quite good agreement with the spectra deduced by Sands [3] and others from various considerations.

Eq. (3) can be evaluated exactly for integral and half-integral values of n, giving for $n = 3$

$$N(\zeta) = \frac{N(0)\{1 - [(mh \sec \zeta/\tau p_{min}) + 1] \exp(-mh \sec \zeta/\tau p_{min})\}}{(mh \sec \zeta/\tau)^2} \quad \text{(5)}$$

In the region of interest here, that is, for $p_{min} \sim 2$ Bev at $\zeta = 0°$, p_{min} is almost directly proportional to the atmospheric absorption depth [4], itself proportional to $\sec \zeta$. Hence $\sec \zeta/p_{min}$ remains very nearly constant, certainly for $0° \leq \zeta \leq 60°$, $1 \leq \sec \zeta \leq 2$, which is the interval in which experimental measurements are made. This means that the numerator in Eq. (5) is essentially constant, and since Eq. (4) can also be shown in this way to hold for $n = 2$ and $n = 4$, it may be concluded that Eq. (4) is quite generally valid in the vicinity of $n = 3$. However, if the thickness of absorber used in the counter telescope is significant compared with the atmospheric absorption depth (1,040 gm cm^{-2} at sea-level), p_{min} is no longer proportional to $\sec \zeta$ and Eq. (4) is not valid. For the thicknesses of absorber ordinarily employed (10-20 cm Pb), this is not a problem.

These results are of twofold significance. First, they give an explanation for the existence of what seemed to be a purely empirical relationship. In addition, a method for analyzing the μ-meson momentum spectrum is provided, with the

resulting spectrum being in agreement with that found by other, much more cumbersome means.

I would like to thank Prof. S. A. Korff for suggesting this problem and for his helpful suggestions.

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SPREAD F OVER HAWAII

By GROTE REBER

Wailuku, Maui, Territory of Hawaii

(Received November 24, 1953)

ABSTRACT

The random variations of intensity of signals from point sources caused by the ionosphere greatly affect studies of cosmic static. One cause of these fluctuations is the condition known as spread F, which indicates the presence of diffuse and irregular echoes from the F-region of the ionosphere. Analyses of spread F over Hawaii were completed for the period 1944-1953. The diurnal and seasonal properties are discussed, and a conclusion is reached regarding latitude and longitude effects. Some properties of scintillations at decameter waves are described.

Introduction

The writer came to Hawaii some time ago to conduct experiments in the field of radio astronomy at decameter waves from the top of Haleakala volcano. One of the limitations of these studies is the random variation of the intensity of the cosmic static caused by its transit through the ionosphere. These fluctuations are a different manifestation of the phenomenon known to ionospheric sounders as spread F. An ionosphere station has been in operation at Kihei, Maui, for nearly ten years. Thus, it seemed that a study of this backlog of data in relation to spread F might be profitable.

Method of count

The year was divided into three seasons, as follows: Summer, consisting of May, June, July, and August; winter, consisting of November, December, January, and February, in consecutive order joining two calendar years; and equinoxes, consisting of March, April, September, and October, of the same calendar year. This division, instead of by months, was chosen because the study was to be statistical in nature and at least 100 days should be available in a group to give significant results. Most of the data were taken from the monthly tabulations of the hourly values of the $F2$-layer critical frequency.

For purposes of this study, the spread-F phenomenon was divided into three categories; namely, faint, moderate, and strong. These agree with the following description.

Spread F is a progressive phenomenon and starts as a small fork in the tip of the trace which does not affect the accuracy of the reading of $f^{\circ}F2$. These are considered faint. Later the spread becomes more pronounced and the edge of the trace is uncertain. Such values of $f^{\circ}F2$ are given in parentheses, meaning doubtful,

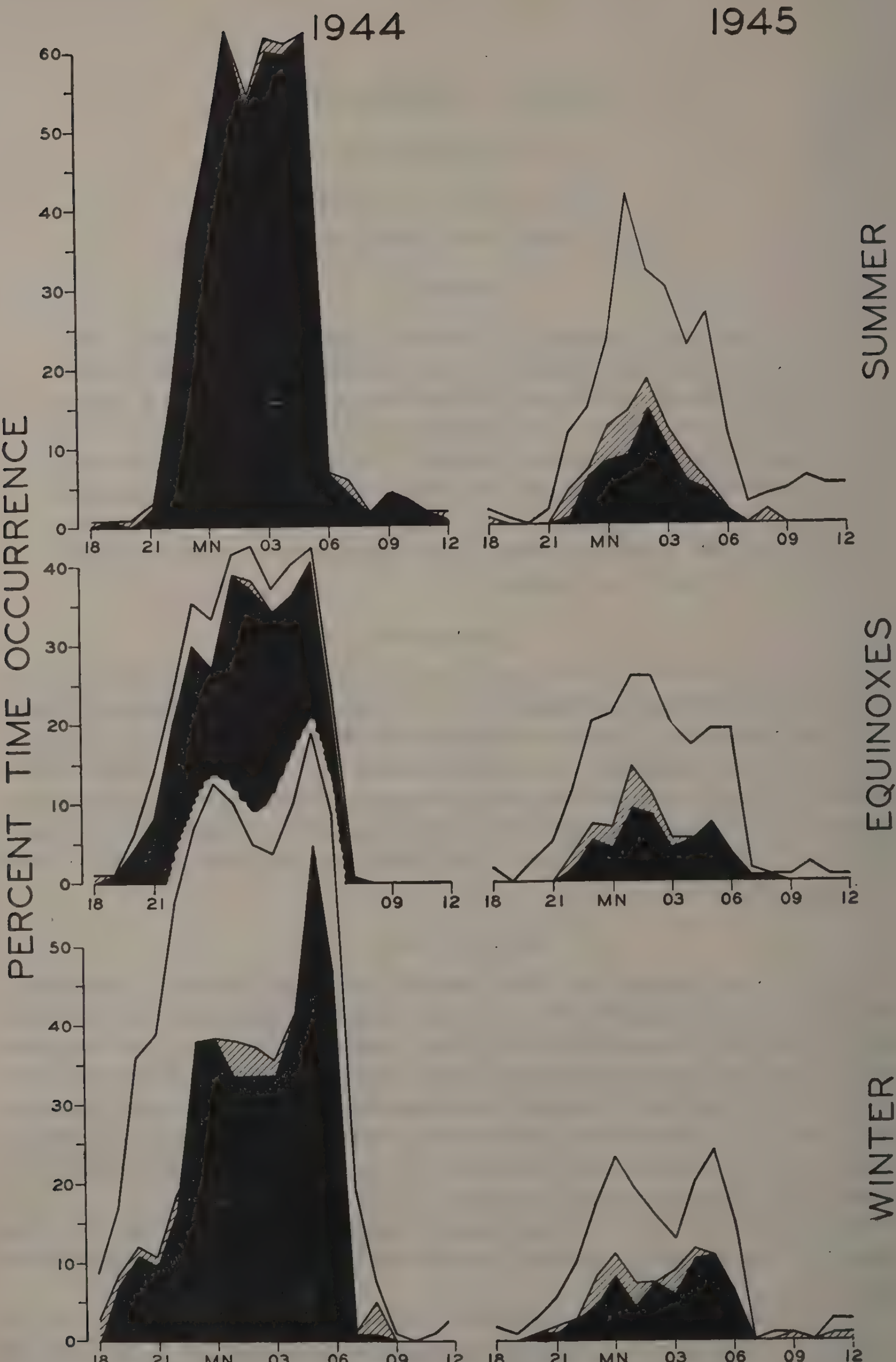

1944
1945
SUMMER
EQUINOXES
WINTER
PERCENT TIME OCCURRENCE
60
50
40
30
20
10
0
18
21
MN
03
06
09
12

FIG. 1.

and are considered moderate. Still later, the trace becomes so dense and broad that no value of $f^{\circ}F2$ may be secured. Such days are considered strong.

The original notations in the data are quite good for the years 1949 and later. Prior to this, there is some doubt into which category the moderate days were placed. There appear to be too many strong days in the early data. Since the division is rather subjective, it seems likely that the early operators tended to merely indicate the presence of spread F if there was any doubt in the value of $f^{\circ}F2$. In general, it seems that this method of analysis has the ability of portraying what occurs in the ionosphere and not what goes on in the apparatus.

Ionospheric apparatus

Prior to June 1949, a British model BAD249 was used most of the time. Thereafter, an American model C-2 and, still later, a C-3 were used. During June and July 1949, the old and new equipments were operated simultaneously. While the duplicate data are limited to these two months, some estimate may be secured of the relative ability of these apparatus to detect spread F. In the strong category, the counts were equal after corrections for missed days. A negligible number of readings fell in the moderate category with each equipment. The weak category showed about twice the number of observations of spread F using the new as compared with the old. On this basis, all the old observations of weak spread F should be multiplied in number by a factor of two in order that they be comparable with the new data. This was *not* done. Examination of the charts will show that such a multiplication will have small effect in most cases and will not affect the results secured. Summer 1949 data as shown were composed of old data for May and new data for June, July, and August. In view of the large amount of spread F observed during 1944 and 1945, it may be assumed that the ability of the apparatus to detect faint spread F had deteriorated somewhat by 1949. This is the main reason that no correction-factor was applied to the old data.

Discussion of results

The ten years of observations are shown in five Figures. The dark shaded portions of the charts represent strong spread F. The moderately shaded and blank portions show moderate and weak spread F, respectively. They are plotted in cumulative fashion.

At all seasons, there is more spread F during solar activity minimum years than at solar activity maximum years. This characteristic is most pronounced during the winter season, where the frequency of occurrence of spread F is over ten times as great at solar activity minimum as compared to solar activity maximum. During the summer season, this ratio is only about two to one, because of a pronounced second-harmonic component in the summer spread-F characteristic. The summer season shows two minima on, respectively, the increasing and decreasing slopes of the solar activity cycle. At these minima, the frequency of occurrence of spread F is about one-sixth and one-third of that at the preceding and succeeding major peaks in the spread-F characteristic. The equinoxes have a spread-F characteristic midway between summer and winter. During the four years near solar activity maximum, there is a nearly constant amount of spread F.

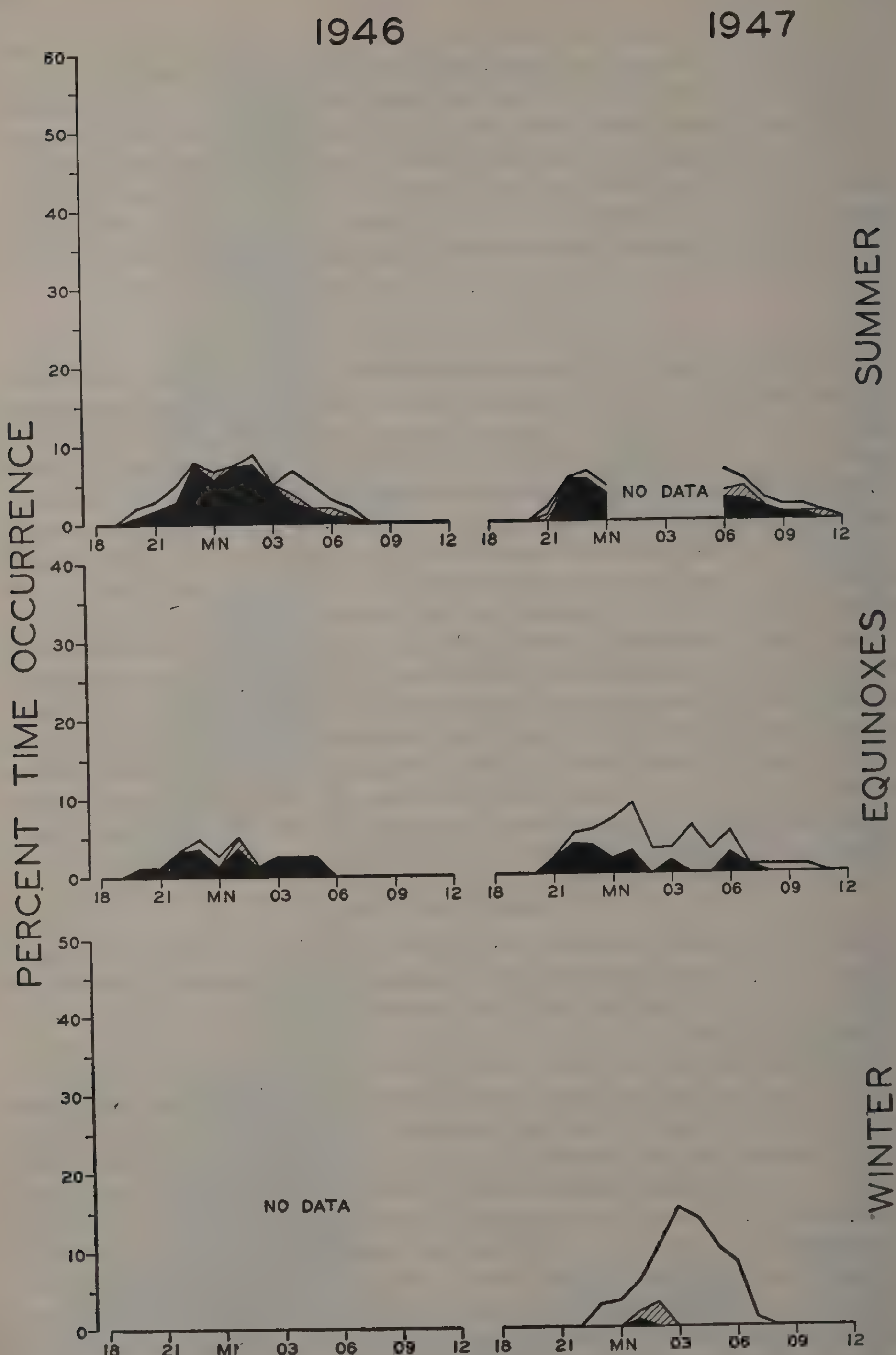

1946
1947
PERCENT TIME OCCURRENCE
SUMMER
EQUINOXES
WINTER
NO DATA
NO DATA
18
21
MN
03
06
09
12

FIG. 2

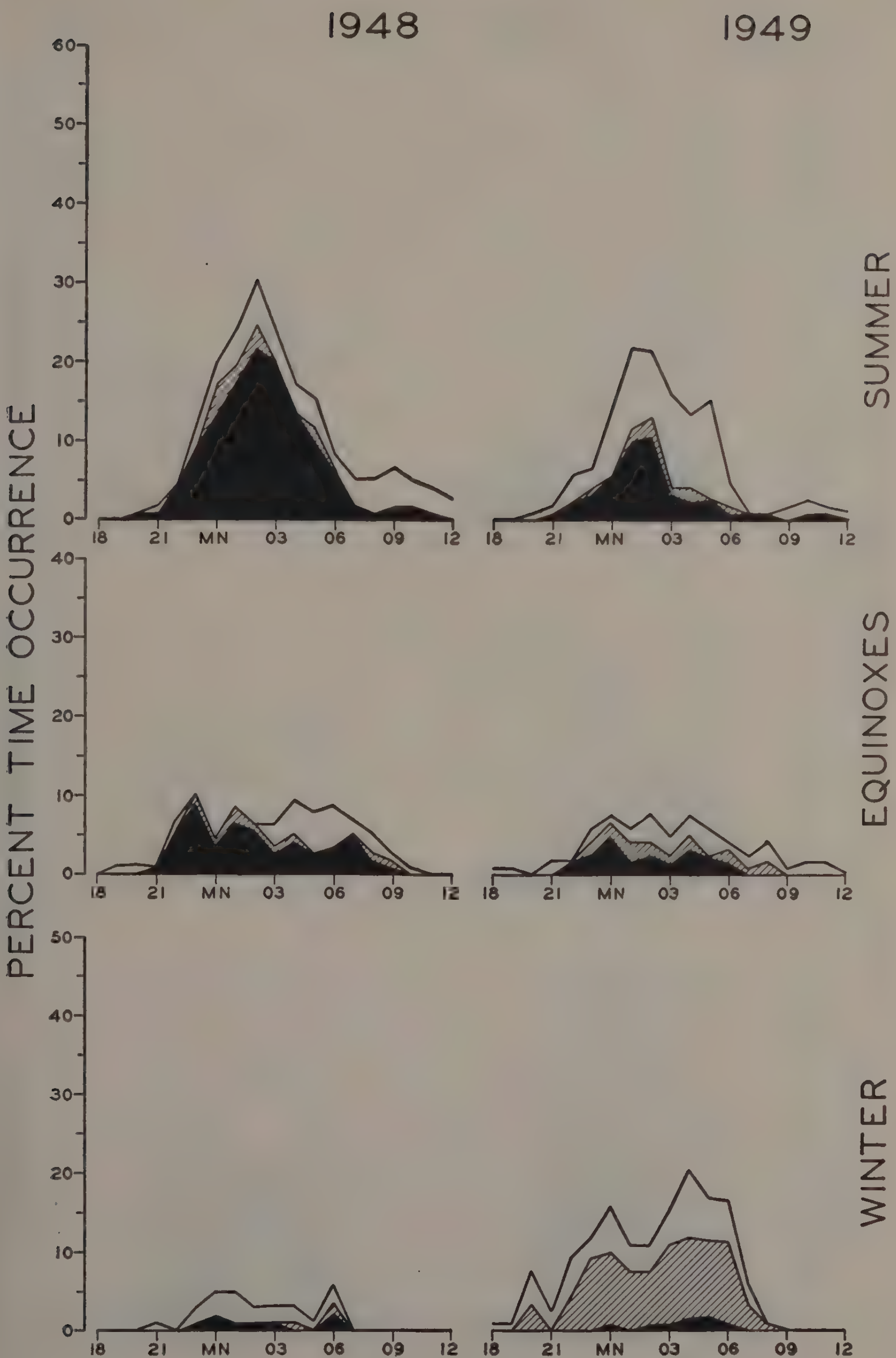
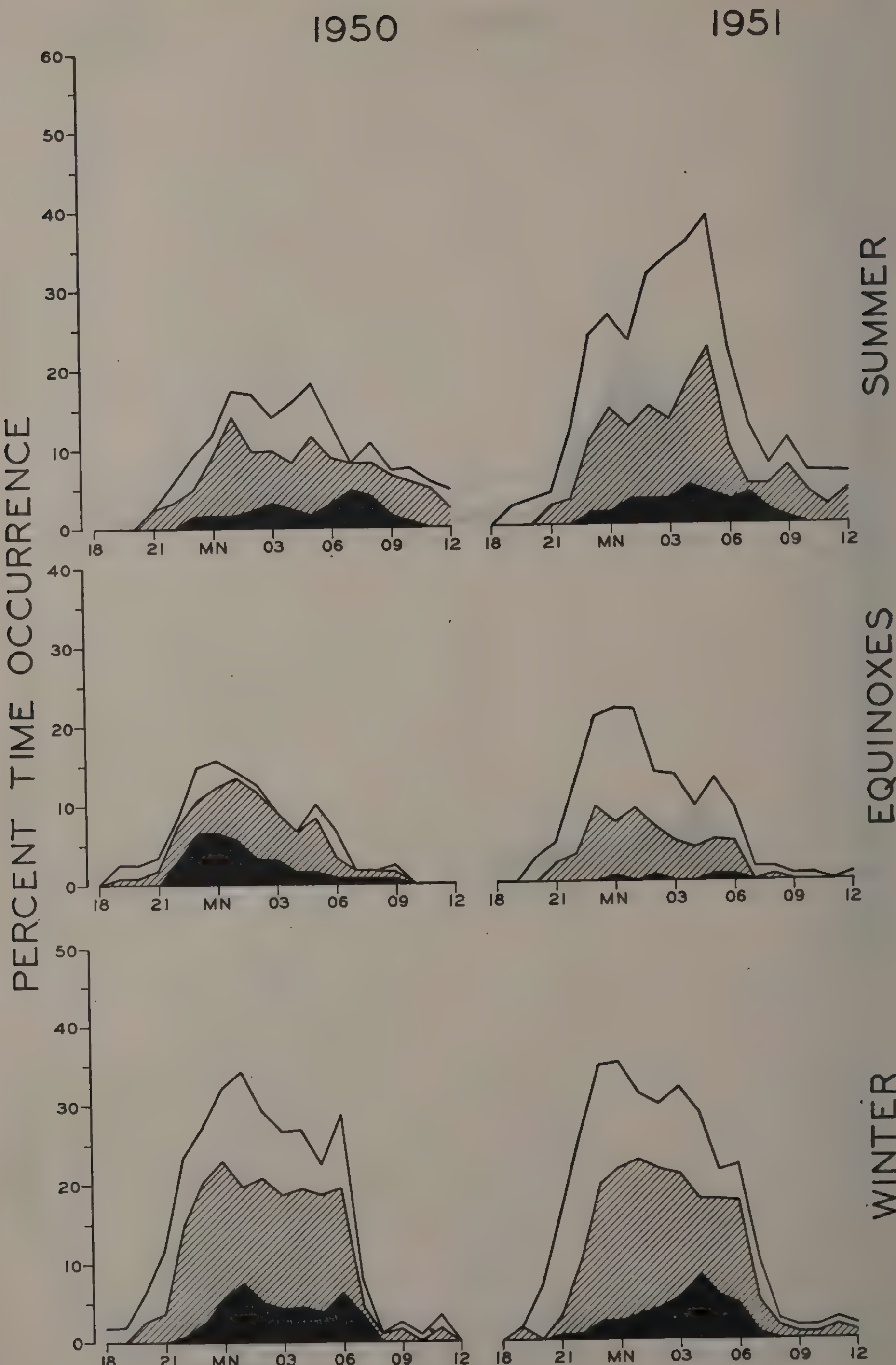

1948
1949
PERCENT TIME OCCURRENCE
SUMMER
EQUINOXES
WINTER
60
50
40
30
20
10
0
18
21
MN
03
06
09
12

FIG. 3



1950
1951
SUMMER
EQUINOXES
WINTER
PERCENT TIME OCCURRENCE
60
50
40
30
20
10
0
18
21
MN
03
06
09
12

FIG. 4

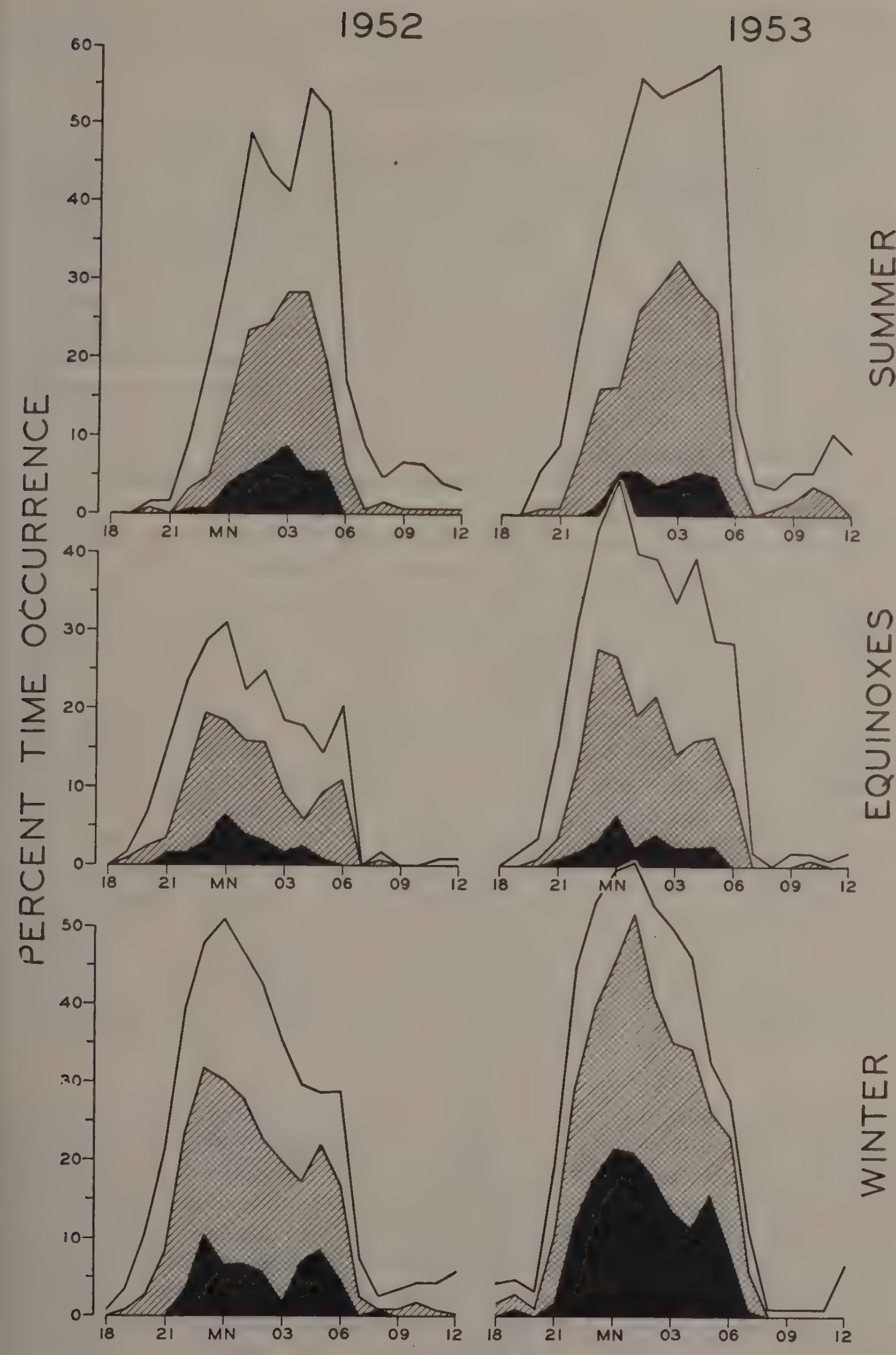

1952
1953
PERCENT TIME OCCURRENCE
SUMMER
EQUINOXES
WINTER
60
50
40
30
20
10
0
18
21
MN
03
06
09
12

FIG. 5

While there is a gradual rise in this phenomenon toward solar activity minimum, it is not as great as in either the summer or winter characteristics. Thus, there is less spread F during the equinoxes than during the solstices at the minimum part of the solar activity cycle.

The diurnal spread-F characteristic always shows a much greater frequency of occurrence at night than during the day. There are two peaks, one near midnight and the other near sunrise. These can be seen best during the winter season when the sun rises late. They can also be seen during summer. However, during this season, the peaks tend to be moved together and at times form one peak near 2 or 3 a.m. The single-peak effect is most pronounced at solar activity maximum. During this part of the solar activity cycle, the equinoxes spread-F characteristic tends to show three peaks. Thus, it may be that this center-peak feature is accentuated during the summer season and overpowers the midnight and sunrise peaks for a year or two at the maximum part of the solar activity cycle.

The hours 13 through 17 were counted, but the results are not shown. In all cases, the amount of spread F during these hours was small compared to the hours displayed and usually was zero.

Correspondence has been exchanged with Harry W. Wells, of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, who has made similar studies of the Huancayo data. There is general agreement in that more spread F is present at solar activity minimum than at solar activity maximum. The Huancayo diurnal characteristic shows a peak at an earlier hour, however. Thus, low latitude stations are similar.

The writer has counted several selected seasons of the Washington data. Peculiarly enough, there is no appreciable difference in the amount of spread F present over the solar activity cycle. To a first approximation, the amount of spread F is independent of the solar activity cycle at latitude 40°.

Correspondence has been exchanged with J. C. W. Scott, of the Defense Research Board of Canada, relative to results at high latitude stations. He states that "spreadiness definitely follows the sunspot cycle, rising as the spot number increases." Obviously, this is exactly the reverse of the situation at low latitude.

Thus, it may be concluded that there is a marked latitude and a less marked longitude effect to spread F. Each part of the earth apparently has its own spread-F characteristic in the same fashion that each place has its own $f^{\circ}F2$ characteristic.

Other features

The correspondence between spread F in the ionosphere and the fluctuations of cosmic static are only general, because the place where the celestial ray goes through the ionosphere is 1,500 to 2,000 miles from Maui. However, during magnetic storms, both manifestations of the phenomenon are at their greatest amplitude. At the peak of such storms, great absorption sets in. Such storm absorption can wipe out even the strongest sources as Cygnus and Cassiopeia. At these times, often the ionosphere traces are very weak, if visible at all. Experience has shown these periods of magnetic storms to be bad periods. They start off with increasing fluctuations. Then absorption sets in, and the fluctuations and celestial sources disappear

for a day or two at the peak of the storm. As storm breaks up, absorption goes away and fluctuations come back. Finally, fluctuations gradually die out.

Acknowledgment

The data used for this study were taken at the National Bureau of Standards' ionosphere station at Kihei, Maui, T.H. Thanks are expressed to the personnel of the station for assistance in the interpretation of the data sheets.

This study is part of an investigation of cosmic static in Hawaii supported by the Research Corporation.

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THE LOCATION OF THE AURORAL ABSORPTION ZONE

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(Received November 25, 1953)

ABSTRACT

A study of data from a chain of radio-wave field-strength recording stations along the 90th meridian suggests that the "auroral absorption zone" coincides with the zone of maximum frequency of occurrence of visible aurora. North of this, there appears to lie a region in which absorption is extremely low.

Although the accuracy of location of the absorption zone is limited by use of fixed transmitters and receivers, as well as by the fact that varying modes of propagation are not taken into account, the indications are that it is somewhat farther north and narrower than has been suggested previously.

INTRODUCTION

A chain of field-strength recording stations along the 90th west meridian, equipped by the Central Radio Propagation Laboratory and operated primarily by personnel of Canada's Department of Transport, has been in operation since early in 1951. The program was set up for the purpose of determining, with somewhat greater accuracy than had previously been possible, the location and extent of the "auroral absorption zone" and manner in which high-frequency radio waves crossing this zone are affected.

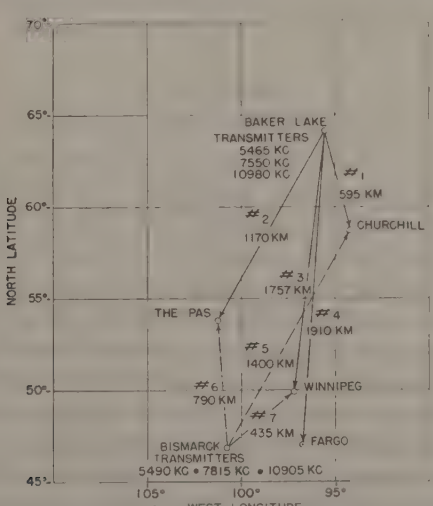


FIG. 1—The north-south chain

The transmitter frequencies, and transmitter and receiver locations, with approximate path lengths, are given in Figure 1. The paths are numbered in order of decreasing mid-point latitude; for example, number 1 is the Baker Lake-Churchill path, farthest to the north, and number 7 is the Bismarck-Winnipeg path, farthest to the south.

The data used were taken from April 1951 to April 1952, although not all the stations were operative for the whole period. It is assumed that propagation conditions are identical for 5,490 and 5,465 kc, for 7,815 and 7,550 kc, and for 10,905 and 10,980 kc, and these frequency pairs will be referred to as 5 Mc, 8 Mc, and 11 Mc, respectively.

METHOD OF ANALYSIS

Although uniformity of receiving and transmitting equipment was attempted, unavoidable differences among the installations of this north-south chain make accurate comparisons of absolute values of field intensity impossible at the present time. However, if a suitable "minimum useful value" of field strength can be selected, comparisons can be made for the various paths and frequencies of the amount of time during which a satisfactory value of field strength was or was not received. The selection of a minimum useful value is obviously arbitrary to some extent; moreover, the use of a single minimum useful value, common to all the recorders, is not entirely correct, because of the equipment differences mentioned above and also because of the effect of angle-of-arrival differences for the various paths. In the interest, however, of simplifying the analysis and avoiding the subjective effect of operator judgment, such a single minimum useful value was chosen as that value of field strength which, in each instance, would produce one microvolt across the input terminals of the receiver.

On this basis, therefore, the hours for which the hourly median value was less than 1 μv were counted, and the "percentage of time out" for each path and frequency was computed. The data so obtained were arranged to give diurnal variations, as well as variations with path length and latitude.

RESULTS

Diurnal variations (smoothed by use of a three-hour running mean) of the percentage of time out are shown in Figures 2, 3, and 4 for the various paths and for the 5-, 8-, and 11-Mc frequencies, respectively. Two curves are shown for each path and frequency. One of these is plotted from data for magnetically quiet days and the other from data for magnetically disturbed days (five internationally selected days of each sort for every month). Although, in most cases, magnetic disturbance appears to be associated with accentuation of the quiet-day diurnal pattern, other effects can also be seen. Only the southernmost paths show a night-time decrease in time out for disturbed days, and this only for the higher frequencies, suggesting that sporadic E is more prevalent during disturbed nights over these paths. For the more northerly paths, for example, number 3 (Baker Lake-Winnipeg), number 4 (Baker Lake-Fargo), the night-time increase in time out is most pronounced at the lower frequencies, indicating that introduction (or increase) of night-time absorption is associated with magnetic disturbance. The Baker

FIG. 2

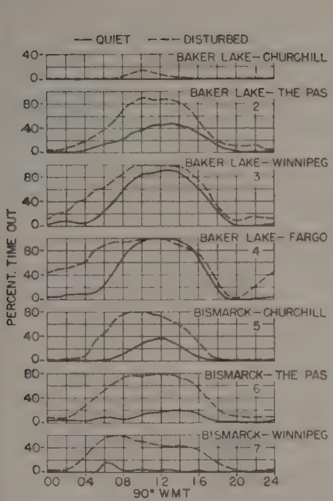


FIG. 3

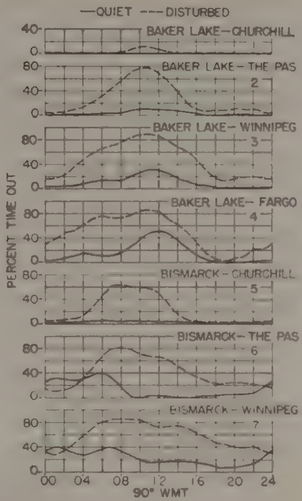
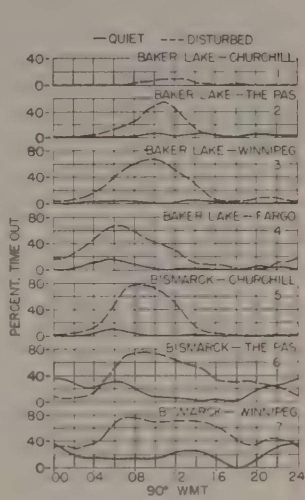


FIG. 4



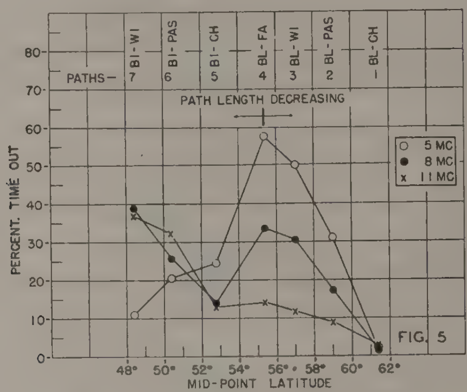
FIGS. 2, 3, and 4—Diurnal variation of the percentage of time out for various paths on 5-, 8-, and 11-Mc frequencies, respectively

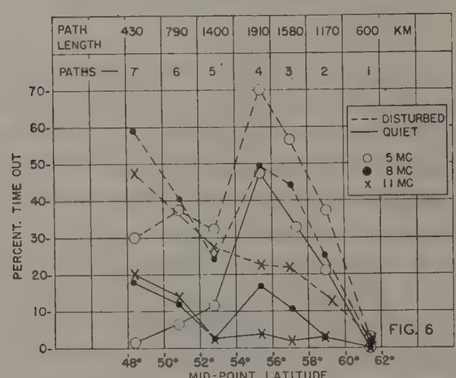
Lake-Churchill path (number 1) is seen to be highly reliable. It is least reliable around midday during disturbed periods, when the time out may reach ten per cent for the lower frequencies. During quiet days, all three frequencies display field strengths greater than the minimum useful value for 100 per cent of the time. This high reliability may be due to nearly continuous activity of sporadic *E* reflections over this path.

Figures 5 and 6 show the variation of percentage of time out with latitude and distance. Complete separation of the two effects is not possible. In Figure 5, all the available data were used, and in Figure 6 the data from ten days of each month (5 quiet and 5 disturbed). Consistency of the data is revealed by the fact that the relatively small amount of data used for each of the curves in Figure 6 (less than 20 per cent of the amount used in Fig. 5) produces no serious inconsistencies.

Comparison of the three curves in Figure 5 shows that the percentage of time out for 5 Mc increases with increasing path length for both the south-north and the north-south transmissions. Some of the increase in time out is no doubt due to increasing distance attenuation (effective at all frequencies), but most of it is probably attributable to the increase of absorption with the length of path in the absorbing region. Observations over the southern paths (transmitters at Bismarck) for the higher frequencies tend to support this hypothesis; the initial decrease of percentage of time out for 8 Mc and 11 Mc, as path length increases, would be expected here, since both frequencies are often above the maximum usable frequency (MUF) for the shorter (southern) paths. Since the MUF increases with path length, the higher frequencies should be propagated a higher percentage of the time for longer paths, provided that the path does not extend into the absorbing region. For path number 1 (Baker Lake-Churchill), high reliability is

shown for all frequencies, indicating the nearly continuous presence of sporadic E over this path, as well as relatively little absorption. The percentage of time out for the longer northern paths shows a marked decrease as frequency increases, indicating that absorption for these paths is important. The sudden change in slope for the S-N paths (at point number 5) suggests increasing absorption with





Figs. 5 and 6—Percentage of time out *vs* latitude of path mid-point

latitude, and the "auroral absorption zone" is indicated as centered perhaps at around 56° north geographic latitude.

Figure 6 shows the effect of disturbances; percentage of time out is greater for all paths and frequencies during disturbed periods.

The location of the absorption zone can be only roughly determined in this manner, for an error is made in assuming that the path mid-point gives the location of the area at which absorption occurs. However, if the mode for every path and frequency were 1-hop-F, for example, the points of interest so far as absorption is concerned would be those at which the wave enters and leaves the absorbing region at a height probably somewhat less than 100 km; in this case then, two points about one-sixth of the way in from the end-points should be considered.

However, available $F2$-layer data indicate that the $F2$-layer MUF is seldom high enough to support the higher frequencies over these paths, and therefore

much of the propagation represented by these plots (particularly on the northern paths) is probably supported by sporadic E. Assuming propagation to be by sporadic E, there still remains the question of whether the 1-hop or the 2-hop mode is predominant. The effects of antenna patterns (transmitting and receiving) and of inverse distance attenuation have been combined to give the following approximate ratios in decibels of receiver input for 1-hop-E (100-km height) compared with that for 1-hop-F (300 km) and 2-hop-E for each of the seven paths in the chain.

Path No.	*Transmitter*	*Receiver*	$20 \log \frac{E(\text{1-hop-}E)}{E(\text{1-hop-}F)}$	$20 \log \frac{E(\text{1-hop-}E)}{E(\text{2-hop-}E)}$
1	Baker Lake	Churchill	10	1
2	Baker Lake	The Pas	−24	−23
3	Baker Lake	Winnipeg	−44	−39
4	Baker Lake	Fargo	−66	−60
5	Bismarck	Churchill	−35	−30
6	Bismarck	The Pas	−3	−8
7	Bismarck	Winnipeg	24	10

It is clear that, if Es is responsible for propagation for paths number 2, number 3, number 4, and number 5, the 2-hop mode, if active, will produce a much greater signal than the 1-hop mode. If it is assumed further that the northern control-point contributes most to the percentage of time out for paths number 3, number 4, number 5—and the southern control point for path number 2—the data giving Figures 5 and 6 may be replotted, giving Figures 7. The southern control-point

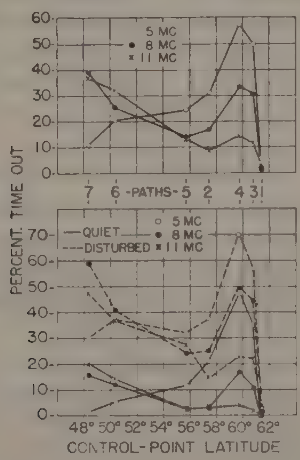


FIG. 7—Percentage of time out *vs* control-point latitude

is used for path number 2, since the northern one lies slightly north of the mid-point of the Baker Lake-Churchill path (number 1) and may therefore be assumed to contribute little to the out-time of the circuit.

Figure 7 indicates that the absorption zone is further north and narrower than is usually suggested [see 1 and 2 of "References" at end of paper].

CONCLUSIONS

It is unfortunate that more certain separation of the effects of distance and of latitude cannot be made. However, the following conclusions appear to be justified.

(1) A region of low absorption and (extremely) high percentage of time occurrence of *Es* exists just north of the zone of maximum frequency of occurrence of visual aurora.

(2) The so-called auroral absorption zone is centered near the center of the visual auroral zone (around 60° north latitude on the 90th meridian).

(3) The auroral absorption zone may be no more than 6° wide in latitude (along the 90th meridian).

(4) In general, for all paths and frequencies, a decrease in circuit reliability is associated with magnetic disturbance.

(5) On the more southern paths, the frequency of occurrence of night-time *Es* is greater during disturbed periods.

(6) Night-time absorption is increased during disturbed periods for paths crossing the auroral zone.

These conclusions serve as a basis for the suggestion that for radio communication across the auroral zone, relay stations located roughly under its center maximum may be used with advantage. For example, (from Fig. 5 or Fig. 7) a usable signal is put into Churchill from Bismarck on 5 Mc about 0.75 of the total time and (assuming reciprocity) into Baker Lake from Churchill 0.98 of the total time, giving contact over-all about 74 per cent of the time. This compares favorably with the 42 per cent given for direct contact between Bismarck and Baker Lake on this frequency. However, for a frequency around 10 Mc, the percentage for direct contact is somewhat higher than for the relay system. Longer paths could give additional useful information on this point, and an extension of the experiment to include at least one path completely inside the auroral zone (receiver at Resolute Bay for example) is desirable.

ACKNOWLEDGMENTS

G. R. Pielmeier has been chiefly responsible for the scaling of the records from the N-S chain. Others were scaled by station personnel at Fargo (North Dakota Agricultural College), and at The Pas (Canadian Department of Transport monitoring station). For this report, Miss K. Wood did most of the data reduction.

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F-SCATTER AT HUANCAYO, PERU, AND RELATION TO RADIO STAR SCINTILLATIONS

BY H. W. WELLS
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(Received December 14, 1953)

ABSTRACT

The scattering of radio waves by the F-region of the ionosphere at an equatorial location (Huancayo, Peru) was discussed by Booker and Wells (1938). Subsequent analysis reveals pronouncedly diurnal, seasonal, and annual characteristics. It is fundamentally a nighttime event, with greatest frequency of occurrence in the period from four hours before midnight to four hours after midnight. The scattering is most prevalent during seasons when the sun is overhead and is infrequently observed during May, June, July, and August (local winter) when the noon solar zenith angle becomes as great as 35°. The relative total annual occurrence of F-region scatter for the period 1938 through 1945 shows low values during 1941-1942, followed by a rapid increase through 1946, which is not closely related to solar activity. The diurnal properties of F-scatter closely correspond to reported characteristics of radio star scintillations with peak activity around midnight. However, the annual or seasonal properties are not in simple agreement.

Some properties of F-region ionospheric scatter as observed at the Huancayo Magnetic Observatory, Huancayo, Peru (12° south) were described by Booker and Wells (see 1 of "References" at end of paper). The authors discussed several forms of regular and diffuse F-region echoes. It was noted that the phenomenon first becomes evident in the late evening hours as the layer heights rise, while its disappearance in the morning sunrise period is associated with the characteristic fall in height and the rapid increase in maximum electron density. These properties suggest that the base of the high scattering region may exist above the regular F-layer. The gradual transition from F-scatter to normal ionospheric conditions is reproduced in Figure 1 (originally presented as Figure 3, reference 1). The authors interpreted the diffuse echoes as scattering due to spatial irregularities or electronic clouds in the F-region, and discussed the limiting conditions for Rayleigh scattering, assuming small linear dimensions of scattering sources compared to wave-length of the probing radio waves.

Subsequent data on F-region scattering have been compiled for the period 1938 to 1945, inclusive, as shown in Figures 2 to 9. Each Figure illustrates the per cent of total time of F-scatter between $18^h\ 00^m$ and $06^h\ 00^m$ for each month of the particular year. The key or legend on each Figure shows the relative percentage by the amount of shading. For example, let us refer to Figure 2, which is

FIG 1—RECORDS SHOWING REGULAR AND DIFFUSE F-REGION ECHOES, HUANCAYO MAGNETIC OBSERVATORY, FEBRUARY 10, 1938; (A) $04^h 45^m$–$05^h 00^m$, (B) $05^h 30^m$–$05^h 45^m$, (C) $06^h 15^m$–$06^h 30^m$, (D) $07^h 00^m$–$07^h 15^m$, 75° WEST MERIDIAN TIME

for the year 1938. We see that during the months of May, June, and July (local winter) no significant *F*-scatter occurred. However, the following months show a rapid increase in the frequency of occurrence, with a strong maximum during the months of November to February (local summer).

The average diurnal characteristics are best described by reference to the Figures for each year. In general, the period from about $20^h\ 00^m$ to $04^h\ 00^m$ is the most favorable for *F*-scatter during November to February. However, during local winter, which is the season of less frequent occurrence, there is evidence that more *F*-scatter occurs from $03^h\ 00^m$ to $05^h\ 00^m$, as in Figures 7 and 8. Some of the years show a tendency during the equinoctial period for *F*-scatter to occur most frequently during the early evening hours, as in Figures 2, 3, 4, 8, and 9.

The contrast between Figures 5 (1941) and 9 (1945) is very striking. *F*-scatter became much more prevalent—a factor of 3 or 4—by 1945. This feature is better illustrated in Figure 10, which presents relative total annual occurrence of *F*-scatter for the entire period, 1938 to 1945. The rapid rise from 1941 to 1945 brackets the period of minimum activity of the last sunspot cycle. The significance, if any, of this observation will be revealed by subsequent analyses.

A basic question remains unanswered: whether or not the disappearance of

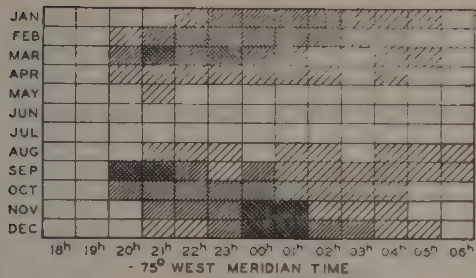

FIG. 2—1938

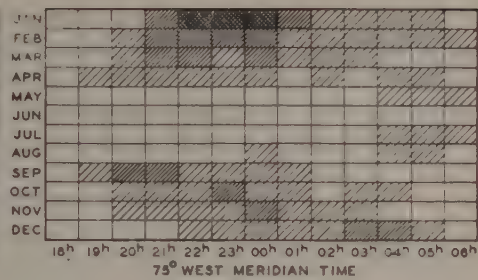

FIG. 3—1939

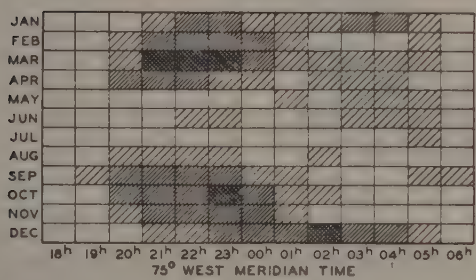

FIG. 4—1940

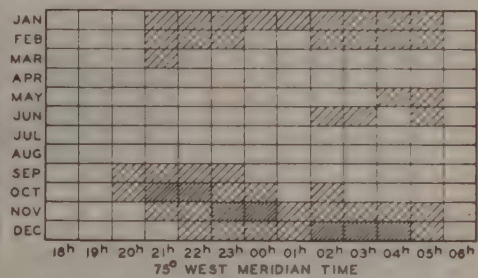

FIG. 5—1941

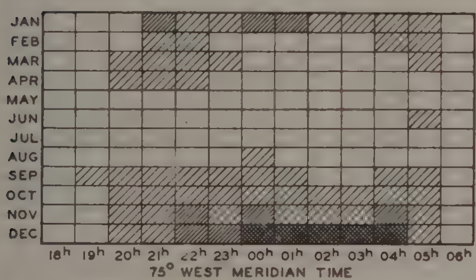

FIG. 6—1942

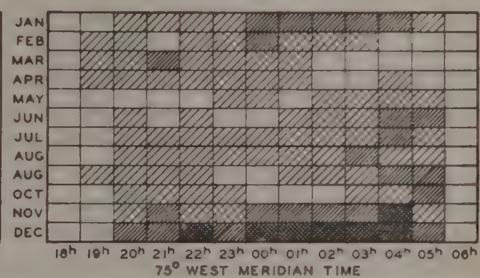

FIG. 7—1943

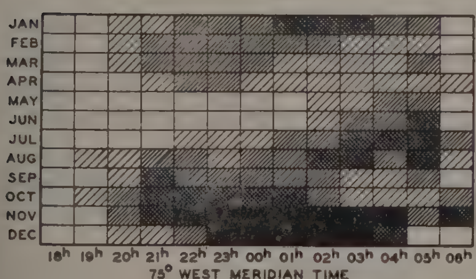

FIG. 8—1944

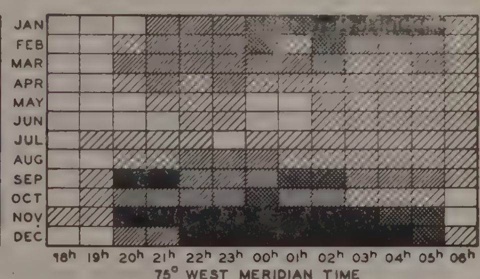

FIG. 9—1945

KEY: 0 TO 9 | 10 TO 29 | 30 TO 49 | 50 TO 69 | 70 TO 100

PERCENTAGE OF TIME WHEN F SCATTER WAS PRESENT

FIGS. 2-9—F-SCATTER, HUANCAYO MAGNETIC OBSERVATORY

F-scatter with sunrise is real or only apparent due to the formation of lower daytime ionospheric layers. The seasonal properties may be examined in a similar manner. Ionospheric heights at Huancayo are appreciably lower during May, June, and July. Is the infrequent observation of F-scatter during these months a result of masking by the lower F-region?

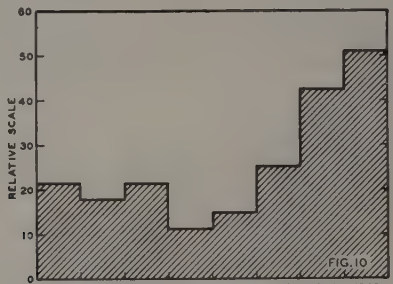

FIG. 10
RELATIVE TOTAL ANNUAL OCCURRENCE OF F-REGION SCATTER, HUANCAYO, PERU, 1938–1945

The condition of F-region, when scatter is observable as in Figure 1, is suggestive of extreme turbulence associated with heating and vertical air movements. One would expect greatest evidence of such turbulence near midday rather than midnight. The data suggest a 12-hour lag, which seems inconsistent. Certainly it is difficult to conceive of a turbulence *of this nature* which is exclusively a nighttime effect. Hence the evidence seems to be in favor of a masking hypothesis.

Recently the observations of radio star scintillations have created new interest in F-scatter. Rapid fluctuations in the intensity of radio waves from discrete sources in the galaxy were originally attributed to variations in the emission of the source. However, the joint experiments of Smith [2] at Cambridge University and of Little and Lovell [3] at Manchester University led to the conclusion that most—if not all—of the irregular variations were due to refraction caused by ionospheric irregularities. Ryle and Hewish [4] examined the diurnal and seasonal nature of radio star scintillations. They established the important fact that there is a genuine diurnal variation in the occurrence of the scintillations. The fluctuations do not exist in the afternoon but build up rapidly between $20^h\ 00^m$ and $21^h\ 00^m$ to a maximum at about $01^h\ 00^m$. They examined ionospheric data and concluded that F-scatter (spread F) and the star scintillations are related to the same primary disturbance and could be accounted for by the same irregularities of ionization in the F-region.

Regarding annual or seasonal variation, Ryle and Hewish state " . . . it is clear that there can be no comparable annual variation of the disturbing influence . . . ." The four sources examined were distributed in declination between $+14°$ and $+58°$. Hence the stellar radiations were incident on the ionosphere at angles between 38° and 6° at time of transit (upper culmination).

The diurnal characteristics of F-scatter at Huancayo in Figures 2 to 9 are in good agreement with the diurnal nature of these radio star scintillations. This is perhaps surprising in view of the differences between observing stations of 64°

in latitude and 5 hours in local time. However, the pronounced seasonal variations of F-scatter at Huancayo have no counterpart in the observed star scintillations. It is difficult to retain the broad features of one characteristic while discarding the other. There are, of course, devices which may be applied to reconcile the observations. For example, we have already questioned the reality of the seasonal effect because of lower observed ionospheric heights which could mask F-scatter at higher levels. But the masking hypothesis of Booker and Wells is based on the assumption that the ionospheric irregularities persist during *all* hours of the day. Therefore, if one can accept the conclusion that both phenomena are the result of the same irregularities of F-region ionization, the masking hypothesis becomes untenable. In that case, one may conclude that the observed *diurnal* features of the F-scatter are real. But once this is accepted, we must, *per se*, also accept the seasonal features as being real—at least for Huancayo.

When the highly irregular features of the ionosphere are considered—even for relatively quiet or undisturbed days—no grounds are left for expecting a similarity in seasonal characteristics of F-region irregularities at locations so widely separated.

In Australia, Mills and Thomas [5] and Bolton, Slee, and Stanley [6] have studied radio star scintillations principally at angles of incidence between 75° and 90°. Their results indicate that E-region irregularities may be the principal cause of scintillations near grazing incidence in the southern hemisphere, but that F-region effects may predominate at angles nearer to the zenith.

Subsequent information on radio star scintillations will contribute to the basic knowledge of the irregular structure of the earth's outer atmosphere. Certain controlled experiments on point sources near the zenith, in conjunction with ionospheric sounders, may help to identify the ionospheric irregularities causing scintillations.

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RADIO ECHOES DURING AURORA*

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(Received December 21, 1953)

ABSTRACT

A reassessment of all the Saskatoon data on 56- and 106-Mc/sec echoes from aurora suggested that some of the 56-Mc/sec echoes might have occurred through backward scatter from the land via the lower part of the ionosphere. These could have originated only through the second-lobe transmission of the radar equipment. Two antennae placed at heights to give the maximum resolution between echoes arising in directions corresponding to the first- and second-lobe signals were used to examine this possibility. The results show that practically all (if not all) the echoes were due to direct reflection from aurora.

Introduction

The very high frequency radio echoes observed during auroral displays [see 1, 2, and 3 of "References" at end of paper] have been assumed generally to arise through either direct reflection or scattering of the waves by ionic inhomogeneities within or close to auroral structures. Recently, Harang and Landmark [4] have suggested an entirely different process for the return of the waves to the transmitting station. From 35- and 74-Mc/sec observations (waves apparently with vertical polarization) in Norway, they concluded that the echoes originate by backward scattering from land or sea via the lower part of the *E*-layer, the ionization of which increases strongly during auroral and terrestrial magnetic storms. This process is apparently necessary to explain their long-range echoes (up to 1,800 km), those of Gatenby and Moran [5] (up to 2,500 km), and of others, since aurora for such ranges would be below the horizon of the transmitting station. It can also explain the absence of short-range echoes when aurora is at a high altitude, if the reflections from the ionospheric layers are assumed to depend on the secant law for critical reflection at oblique incidence.

Particular attention was given to the location of the echoing medium during the earlier work at Saskatoon. Numerous comparisons of range-azimuth plots of the echoing media (determined by radar equipment) with distance-azimuth plots of auroral structures (determined from single-station photographs by assuming a height of 100 km for the lower edge of the aurora) were made. Without exception, an echoing region matched extremely well with some part of an auroral structure (see Fig. 4 of reference [3]). In fact, the agreement was so good that for most of the later work it was assumed that echoes always originated from aurora.

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By doing so, it was possible from the echo data to deduce auroral heights and height distributions in good agreement with values obtained by other means (see Table 5 and Fig. 5 of reference [3]). The fact that echoes were never observed without aurora somewhere in the general direction toward which the radar pulses were being transmitted was an additional reason for accepting this assumption. Unfortunately, except for a small number of exploratory runs at the beginning of the investigation, observations were limited to ranges out to about 1,100 km—about the limit of direct echoes from aurora. As a result, long-range ground-scatter echoes which might have been occurring would not have been observed.

For reasons implied in the previous paragraphs, all the accumulated data were reassessed, taking into account the possibility that some, or all, of the echoes had arisen through ground scatter. In the case of the 56-Mc echoes, it was found that echoes could have occurred through direct reflection from aurora of the primary-lobe radiation, or through ground scatter of the secondary-lobe radiation. To distinguish between these possibilities, two identical 56-Mc/sec receiving antennae were placed at heights to give optimum resolution between angles of arrival of the primary- and secondary-lobe radiations. Also, the operating range of the equipment was extended out to about 1,400 km. A sufficient number of echoes has now been observed on the modified equipment to conclude that practially all (if not all) the echoes that have been observed at Saskatoon occurred through direct reflection from ionized regions associated with aurora.

Reassessment of data

Photographs of aurora, taken simultaneously with the reception of 106-Mc echoes, were made with a f/1.25 auroral lens that had sufficient light-gathering power to yield well-defined outlines of auroral structures and star backgrounds with moderate exposures. While usable photographs were not available for all the echoes, the ones that were used invariably showed aurora close to the positions from which the echoes would have come by direct reflection of primary-lobe radiation. In all cases, the operating ranges were too short for the detection of the return of primary-lobe radiation by the ground-scatter process.

Photographs of aurora, taken in conjunction with observations of 56-Mc echoes alone and of 56- and 106-Mc echoes alternately, were made with a 16-mm movie camera. While these pictures were usually good enough to verify the presence of aurora in front of the radar antennae, most of them could not be used for the exact plotting of auroral contours. A considerable number showed auroral arcs at altitudes favourable to the return of second-lobe 56-Mc/sec radiations by the ground-scatter process. Some of these also failed to show distinct auroral forms at the lower altitudes needed for direct reflection of the echoes. This failure cannot be accepted as definite evidence for ground-scatter echoes, since the light from low-altitude aurora is often reduced to about a hundredth of the value of zenithal aurora because of scattering and absorption in the lower layers of the atmosphere.

The echoing process for the 56-Mc echoes was examined next by comparing the frequency of the occurrence of the echoes with the radar sensitivity for different ranges. Figure 1*b* shows the frequency of occurrence against range plot. This plot has not been corrected for beam coverage or variation of echo occurrence

with geomagnetic latitude—corrections that shift slightly the occurrence curve toward lower ranges. Figure 1a shows the radar sensitivity against range plot for direct reflection. To plot such a curve, it is necessary to assume some height for reflection—in this case 120 km. This curve is based on reflections from a discrete target. If it is assumed (as is more likely) that the reflecting regions consist of

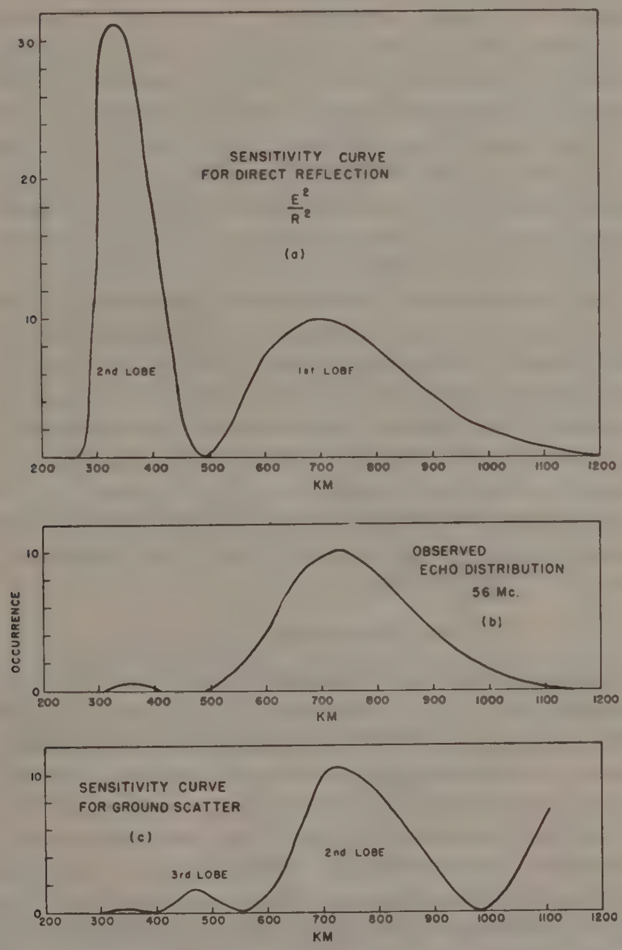

FIG. 1—(a) The radar sensitivity against range plot for 56-Mc echoes by direct reflection; (b) the observed frequency of occurrence of 56-Mc auroral echoes plotted against their ranges; and (c) the radar sensitivity against range plot for 56-Mc echoes by ground scatter

random distributions of reflecting volumes, the shape and amplitudes of the peaks are altered somewhat. The most notable change is a considerable decrease in the amplitude of the second-lobe sensitivity. Figure 1c shows the radar sensitivity against range plot for the ground-scatter process. This curve was plotted also by assuming a height of 120 km for the ionospheric reflections. While the positions of its peaks and nulls are quite accurate, its shape and relative peak amplitudes

can be changed appreciably, since they depend on a reflection factor at ionospheric levels and a scatter factor at the ground. If the sporadic-E ionic clouds are assumed to have a unit coefficient of reflection and the secant law is applied, the sensitivity for longer ranges is increased and the sensitivity of the third lobe is reduced. If the theory of partial reflections from a stratified layer, as proposed by Feinstein and Salzberg [6], is applied, the reflection coefficient varies inversely with the cube of the cosine of the angle of incidence. This reduces the sensitivity of the third lobe and increases the sensitivity of the first lobe. In addition, some factor is needed to allow at least approximately for the variation of back scatter with angle of incidence at the ground. Figure 1*c* is based on the inverse cosine-cubed relationship for each ionospheric reflection, and a variation of the back scatter according to the cosine of the incident angle. Each curve is normalized to an arbitrarily selected value of 10 for the maximum in the 600- to 800-km range.

A comparison of the curves shows that direct reflection is statistically preferable. The nulls and peaks in the observed echo distribution curve agree well with the corresponding nulls and peaks in the radar sensitivity curve for direct reflection. Except for the second-lobe peak, this is not the case for the radar sensitivity curve for ground scatter. An alternative possibility is that the main group of echoes occurred through ground scatter, and the small group of short-range echoes occurred through direct reflection because of the high second-lobe sensitivity for reflection. Still another possibility is that the main group of echoes was due to both reflection and ground scatter, since the observations did not extend to ranges of about 1,400 km, where another peak occurs in the sensitivity curve for ground scatter, and where another group of echoes should have been observed if the ground-scatter process is the dominant one.

Further instrumental observations

An instrumental method was developed to resolve the uncertainty brought out by the reassessment of the observational data. The existing 56-Mc antenna (height of 2.39λ) was used to transmit horizontally polarized signals. Two identical receiving antennae, one at a height of 0.81λ and the other at 2.0λ, were used to detect echoes. This arrangement gave the optimum resolution between the angles of arrival of first- and second-lobe signals. The two signals were brought to a radio frequency switch at the receiver. This switch was used also to displace vertically the trace on the cathode-ray tube (range-amplitude display) in synchronism with the switching of antennae, so that the amplitudes of the two sets of signals could be readily compared. Since the instantaneous signals are subject to rapid fluctuations because of the large number of incoherent reflectors, and since the phase fluctuations of the signals at each antenna are different, measurement of the true amplitude ratio of the signals requires a short period of integration. This was accomplished through the time of exposure (about 5 sec) of the recording camera. The range of the equipment was extended out to about 1,400 km.

Figure 2*a* shows a conventional plot of the variation of the strength of the received signal for different angles, the solid curves for the lower antenna and the broken curves for the upper antenna. Figure 2*b* is a rectangular plot of the same values—a plot that is easier to use in the discussion which follows. Below the

plot are shown the ranges for direct reflection and for ground scatter, corresponding to an assumed height of reflection of 120 km. It can be seen from these plots that for direct reflections at ranges of 600 to 1,000 km the signals on the upper antenna will be stronger than for the lower antenna. Similarly, for ground scatter at these ranges, the signals on the upper antenna will be weaker than for the lower antenna.

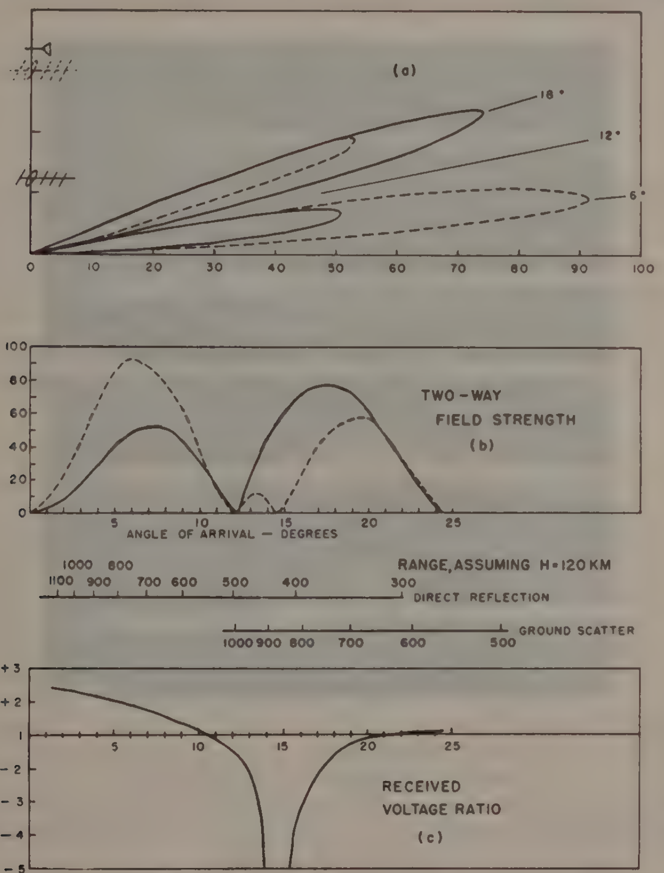

FIG. 2—(*a*) A conventional plot of the relative strengths of the received signal from different angles—the solid curves for the lower antenna and the broken curves for the upper antenna; (*b*) a rectangular plot of the same values as shown in Figure 1*a*, with the ranges for direct reflection and for ground scatter shown below it; and (*c*) the ratios of the received voltages corresponding to different angles of arrival—computed by dividing the larger voltage by the smaller and plotted by assigning a ratio a positive value when the signal on the upper antenna was stronger, a negative value when weaker

Figure 2*c* shows the ratios of the received voltages corresponding to different angles of arrival. A ratio was computed by dividing the larger voltage by the smaller. When the signal on the upper antenna was the stronger, the ratio was given a positive value; when weaker, a negative value. It is evident that for first-lobe reception (signal returned by direction reflection), the ratio of the signal on the

upper antenna to the one on the lower antenna will increase with range; whereas the reverse will be the case for second-lobe reception (signal returned by ground scatter). It is also evident that a reasonably accurate determination of the angle of reflection can be made for amplitude ratios that are changing rapidly with angle. By combining the angle determined in this way with the observed range, the height of the reflecting medium can be computed. Figures 3 and 4 are photographic

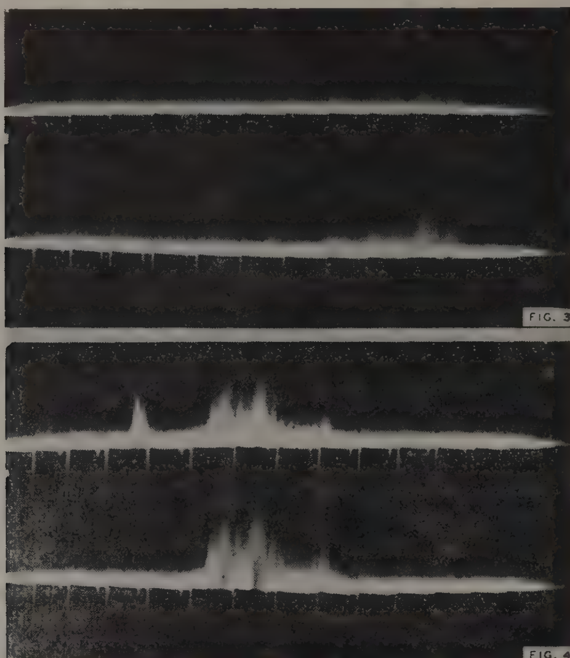

FIG. 3

FIG. 4

Fig. 3—A typical range-amplitude record for echoes at about 1,000 km; the lower display is for the upper antenna; the relatively large amplitude of the echoes on the upper antenna indicates arrival at low altitudes by direct reflection

Fig. 4—A typical range-amplitude record for short and medium range echoes; the relatively large amplitude of the echo at 380 km on the lower antenna indicates arrival at altitudes of about 14° by direct reflection

copies of typical records with the echoes extending toward both limits of the ranges over which echoes have been observed. These show clearly that direct reflection is the process. Thus far, examination of 180 of these photographs has failed to show any evidence of ground scatter. An echo with a range beyond 1,200 km has still to be observed.

Figure 4 shows echoes arriving at angles up to 18° at a range of 340 km. The null in the radiation pattern is quite evident. At 380 km, the amplitude ratio is essentially in the infinite ratio portion of Figure 2*c*. This corresponds to an angle of arrival of about 14°.5 and a height of 105 km (corrected for atmospheric refraction) for the reflecting medium—a value corresponding closely to the most frequently-occurring height for the lower limit of aurora.

Conclusions

From the reassessment of the accumulated data on radio reflections from aurora, and from the differential output observations with two antennae, it seems certain that practically all (if not all) the echoes observed with frequencies of 56 and 106 Mc/sec at Saskatoon were due to direct reflection from auroral structures. The differential output method of detecting the echoes is being continued to see if ground-scatter echoes occasionally occur on 56 Mc/sec. Such occurrence is not unlikely, since ground scatter is known to take place under normal ionospheric conditions on high frequency transmissions up to about 30 Mc/sec.

Acknowledgments

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NOTE ON THE NATURE OF A SEISMOGRAM—I

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(Received April 29, 1954)

ABSTRACT

Coherent patterns obtained from multiple seismograms have indicated that there could be strong conversion of compressional waves to surface waves at the earth's uneven surface. In addition, ground motion studies have shown the presence of Rayleigh waves after the P arrival and before the S arrival. This conversion could account for much of the ground motion in a typical seismogram.

Introduction

Lamb [see 1 of "References" at end of paper] noted in 1903 that the surface motion from an idealized, remote impulsive surface disturbance in a semi-infinite medium, which he partially derived and estimated from the theory of elasticity, did not agree with observation. Instead of a few marked motions associated with the simple wave motions, there was a continuous motion of the earth once the first impulse arrived and this continued until after the slower surface waves had already arrived.

In our search [2] for reflections and refractions of seismic waves from buried crustal structures using explosions as the source of the seismic waves, we too were baffled by the complexity of a typical seismogram. Of all the hypotheses we had tried to explain this phenomenon, the idea that it was some sort of scattering [3] seemed most attractive. General scattering of P waves did not seem to explain all the observations, particularly the curious coherent patterns observed in multiple seismograms [4]. These multiple seismograms were the recordings of arrays of seismometers extending over one to two kilometers of the earth's surface. They were set up in order to get correlated signals from buried structure and thus discriminate against random scattering. Instead of observing occasional correlations, we observed repeated quasi-coherent patterns as if there were repeated signals coming from the source. These signals came in after the first arrival (compressional wave) and continued until the arrival of the shear-Rayleigh complex and longer. They varied in intensity from place to place, sometimes prominent and sometimes barely discernible.

In order to explain this phenomenon, we hypothesized that the compressional waves impinging upon the earth's surface from below, at a point many kilometers distant from the shot, were partially converted into Rayleigh waves. The Rayleigh waves then carried the initiating shape of the P wave disturbance of the surface, which had itself passed on to more distant points, along the nearby earth's surface.

Thus, the multiple seismogram patterns were phase diagrams and, though their phase velocity on the seismogram was that of the first arrival, their group velocity was that of the slower surface wave. Such a system on a rough earth surface would account for the patterns observed in the multiple seismograms between P and S. After S it was thought there could be back-scattered Rayleigh waves. The classical picture of Knott [5] does not allow for such conversions. However, the work of Nikano [6] implied that if there were extreme curvature of the wave fronts such conversion might take place. As the earth's surface is not smooth, the wave front at the surface could be considered as extremely irregular. Our wavelength is about 700 meters for P waves near the surface.

A non-directional, portable strain seismometer, after Benioff [7], was constructed and used last year in conjunction with a vertical velocity seismometer to measure the ground motion. Although in many places the exposed surface rock does not strain and thus is clearly not well connected to the underlying strata, we did succeed in finding three localities in which we obtained usable records. In one place, 100 km from the source, 90 per cent of the seismogram between P and S indicated Rayleigh wave motion. In two places, the motion was obscure; all possible combinations of ground motion seemed to be in evidence; a small fraction showed Rayleigh-type motion. Since Rayleigh-type motion appeared before the epoch of the direct Rayleigh wave, there must be conversion—at least in some places.

At this point in our studies, it was thought desirable to try a series of model experiments.

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NOTE ON THE NATURE OF A SEISMOGRAM—II

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(Received April 29, 1954)

ABSTRACT

Model experiments have experimentally verified Lamb's calculation. Also they have corroborated the conversion hypothesis of Part I, in which compressional waves produce strong Rayleigh waves at a surface discontinuity. In addition, the reciprocity theory is shown to be valid, and the generation of Rayleigh waves from deep focus sources has been studied. Apparently, any obstacle in the path of a plane (compressional) wave acts as a scattering center, and if at the surface produces Rayleigh waves.

Single unidirectional impacts are made at a point on a steel block by brief voltage pulses applied to a piezoelectric crystal of barium titanate. The seismic waves are received and converted to electric pulses by another barium titanate crystal. Pulse amplifiers ("500" type) with good response from a few kilocycles per second to 6 Mc/sec amplify the pulses, which are displayed by an oscilloscope triggered by the transmitter pulse. Pictures are taken by an exposure to the repeated traces of from 500 to 2,000 repeated pulses. The electrical pulses are of 0.4 μ sec duration for the velocity seismogram or a Heaviside-type step pulse with a rise time of about 0.4 μ sec for the displacement seismograms. The crystals have effective dimensions of 1 to 2 mm, but lengths of 5 cm to eliminate reverberation effects. The separation of transmitter and receiver is from 5 to 15 cm, usually. The compressional pulses travel 0.61 cm/μ sec (6.1 km/sec). The wavelength of the P wave appears to be about 0.7 cm or less.

Surface waves

Figure 1 is a reproduction from Lamb's original publication of the surface disturbance due to a point impulse. On Figure 2 is a description of the salient parts of the seismogram. Figure 3 is a seismogram taken with transmitter and vertical component receiver spaced 5 cm apart (Δ) on a large steel block. The upper left trace, *a*, is the displacement as a function of the time, and *b* is the same function with amplification 10 times that of *a*. Trace *c* is the velocity of the surface particles, and *d* is the same function amplified 30 times. Note that the essential details agree well with Lamb's theoretical descriptions. There is a single P pulse at about 8 μ sec, followed by a long smooth wave. In the experimental case, there is no easily observed S wave. Then there occurs at 15 μ sec a large Rayleigh pulse. The record after this is fairly quiescent for a few microseconds; then all manner of reverbera-

tions set in, detectable for as long as 0.3 second. Similar seismograms have been made out to $\Delta = 15$ cm, which are quite like these, though the long tail after the compressional wave takes on a more complex form, for reasons not yet understood.

The next test was to see the effect upon the seismograms of surface discon-

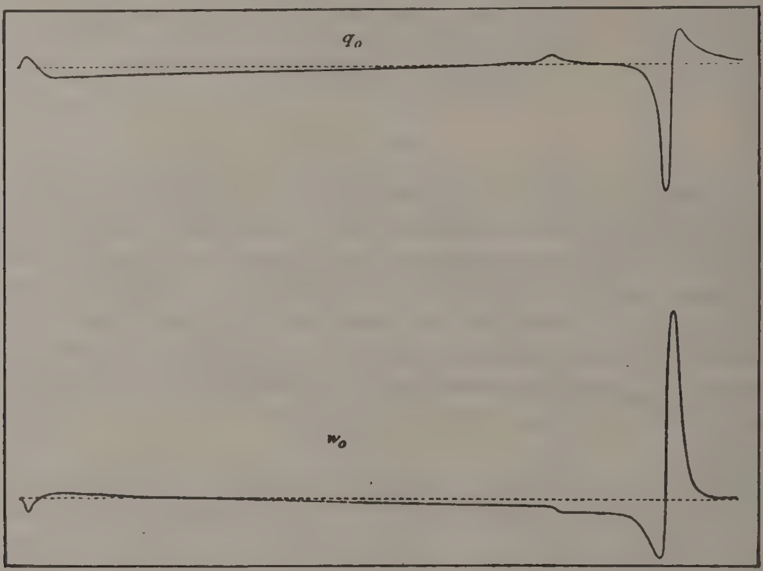

Fig. 1—Lamb's (1903) ground motion from a distant impulse; upper curve = horizontal motion, lower curve = vertical motion

tinuities. The first test, on a small steel block with many small holes of diameter 3 to 7 mm drilled into the surface to a depth of 3 to 7 mm between transmitter and receiver, resulted in a completely changed seismogram, with several oscillations between P and R—approaching the ones found in the usual field observation. Although this test showed the importance of the surface, it could not be used to determine the mechanism. A disturbing center, inserted to introduce disturbing conversion or scattering wave components, made in the form of a brass bar, 3/8″ by 1-1/4″ and 4″ long, was placed with its small face in contact with the smooth (undrilled) surface of the large steel block, midway between transmitter and

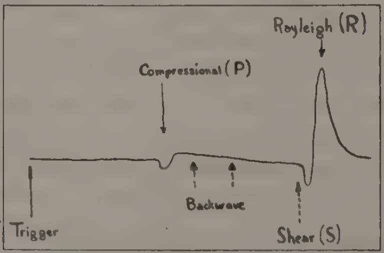

Fig. 2—Diagram of seismogram; the point "trigger" denotes the application of the voltage pulse to the "send" crystal

receiver, as shown in Figure 4. In order to facilitate surface contact, a soft grease was used between the surfaces. When this disturbing block or "artificial mountain" was in place, the seismograms were appreciably altered, as shown in Figure 4, in which are presented seismograms of the undisturbed and "brass block" disturbed

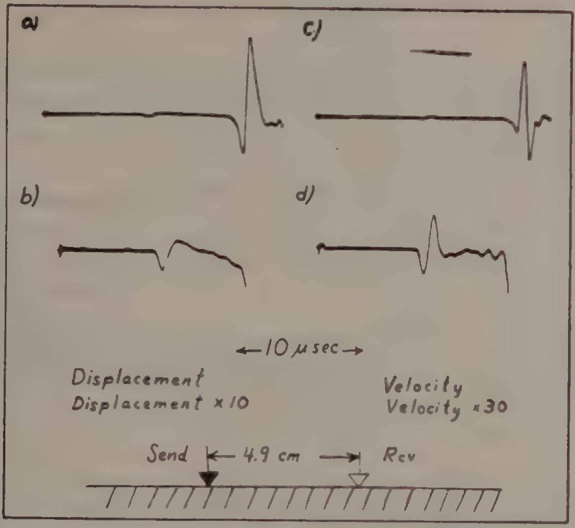

FIG. 3—Model seismograms showing the surface motion from a point impact, as in Lamb's theory; source size much less than the wavelength and reception distance much greater than the wavelength

seismograms. Since there was in this case only one scattering or conversion center, certain properties of the mechanism can be deduced. Most of the disturbance appears just before the Rayleigh wave, and, since the source was not disturbed, the P wave must have produced at the scattering center a slower wave. Assuming

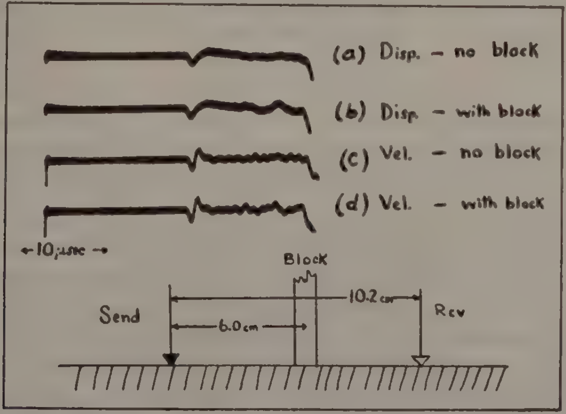

FIG. 4—Seismograms showing the effect of a surface disturbance by a surface obstacle of wavelength dimensions; the compressional wave produces a Rayleigh wave at the obstacle

this is a Rayleigh wave, the time of first disturbance is computed to arrive at 22.5 μ sec. It is observed at 21.7 μ sec. The agreement is good. Therefore, the major effect of a surface discontinuity is to produce a converted Rayleigh wave. This is in agreement with our hypothesis, which was based upon our field experience.*

Transmitter at depth

Experiments were conducted with the transmitter in a hole up from the bottom of a steel block. Seismograms are shown in Figure 5 for these cases. The characteris-

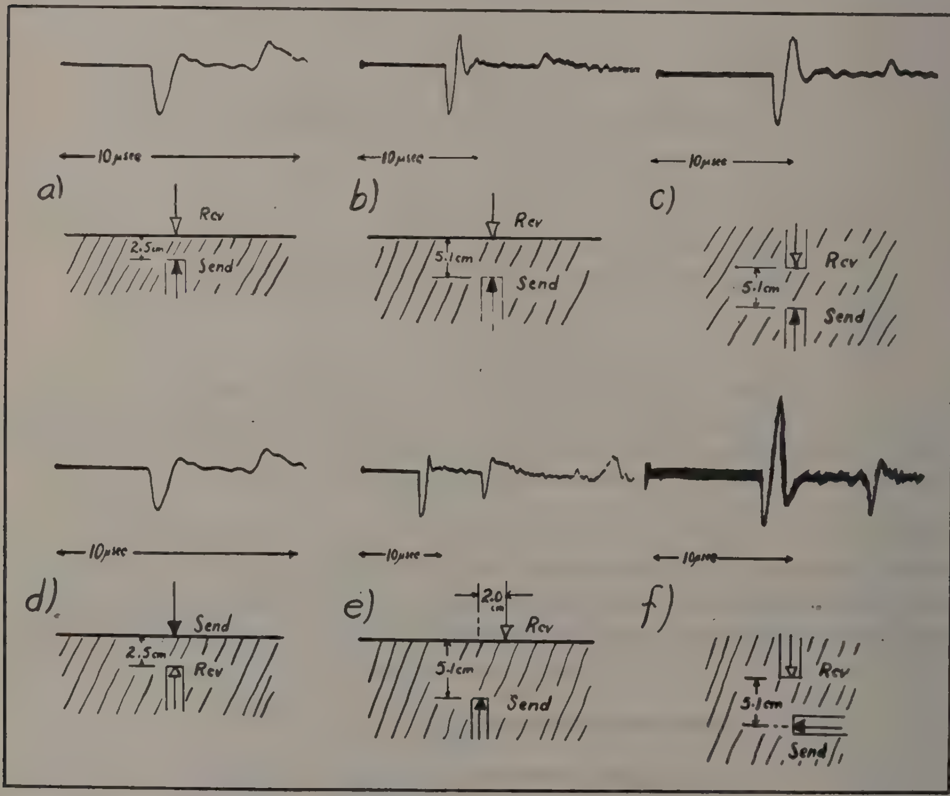

FIG. 5—Various experiments with deep focus source (and receiver); *a* and *d* show "reciprocity"; all displacement seismograms

**Note added in proof:* For the case of the surface transmitter and the surface receiver, in addition to $P \rightarrow R$ conversion at a surface discontinuity, the inverse $R \rightarrow P$ conversion at a surface discontinuity has been verified. If the scattering center is placed almost midway between transmitter and receiver, the amplitudes of the transformed waves at the receiver are apparently identical. Consider the amplitude of the P wave at the detector as a standard. Then in this experimental arrangement the P wave incident at the scatterer transforms into an R wave whose amplitude at the detector is slightly less than that of the standard. The R wave incident upon the scatterer (of much greater amplitude than the incident P wave) transforms into a P wave whose amplitude at the detector is again slightly less than that of the standard.

These conversion waves appear to have marked directional characteristics which need to be investigated.

ties of the traces with transmitter 2.5 cm (Fig. 5*a*) and 5.1 cm (Fig. 5*b*) below the surface are markedly different from that with transmitter on the surface. The Rayleigh wave is diminished by a factor of 20 to 50 relative to the P wave. The disturbance (as diagramed in Fig. 6) after the P wave is greatly diminished (a trace of it is

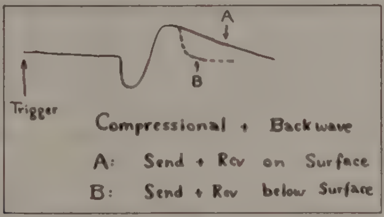

FIG. 6—Diagram indicating disappearance of the backwave as receiver is changed from surface to depth, thereby indicating surface nature of this wave

observable at high amplification). Thus, as Nikano [1] had shown, the Rayleigh wave diminishes with focal depth. In addition, the behavior of the wave just after the P wave indicates it too is a surface wave—probably a Rayleigh wave.

Reciprocity

At this point, the electrical connection to the transmitter in the hole and the receiver on the surface were interchanged without changing any setting in the rest of the equipment. The resultant seismogram is shown in Figure 5*d* and is a close replica of the seismogram in Figure 5*a*. The result is that the Helmholtz reciprocity relationship, as for the sound in air [2], holds for the conditions in this experiment in a solid.

Interior transmitter and receiver

The seismograms from transmitter and receiver, both in deep holes and separated 2″, are also shown in Figure 5. There are two cases: the crystals coaxial (Fig. 5*c*) and perpendicular (Fig. 5*f*). The received P pulse at 8 μ sec is single and shows no trace of the long wave seen in surface transmission and reception, further indication of the surface nature of this wave. Figure 5*f* shows, perhaps, a small shear wave.

Deep focus, surface scattering and reception

The transmitter had a focal depth of 5.1 cm, the receiver a Δ of 9 cm. The brass block again as a scattering center, placed almost at the epicenter, made a disturbance of the seismogram in much the same way as for the surface experiment. Here again, a time calculation shows the disturbance should occur in 16.2 μ sec if a P-P effect, 22.6 μ sec if a P-R effect. It occurred at 21.8 μ sec, showing it is, indeed, a P-R effect. Thus, an interior wave at a surface scattering center makes a surface Rayleigh wave. By reciprocity, a surface Rayleigh wave scatters conversion P waves at a disturbance point. Thus, the concept of the interaction of plane P or S waves upon surfaces must be broadened to recognize the effect of scattering centers as new sources producing not only P and S non-plane waves, but also more complex waves, such as Rayleigh waves.

Conclusion

This note is intended to be brief and only a small number of conclusions may be stated.

The estimate by Lamb of the surface effect of a point disturbance is examined experimentally. The results are found in all respects to be in qualitative agreement with Lamb.

Surface irregularities are found to alter the simple wave patterns, making them conform to field seismograms. This is in agreement with a hypothesis previously deduced from field experience. The P wave makes R waves at a surface scattering center.

The long tail after the first arrival in Lamb's pictures is shown to be a surface wave, not a body wave.

Reciprocity is shown to hold for the particular models used.

Scattering centers at a surface cause conversion of P to R and R to P waves, respectively.

Thus, the complex nature of a seismogram can be attributed in part to the interaction of seismic waves with surface irregularities and the resultant generation of surface waves. Just what fraction is due to surface and volume scatterings remains for future investigation to determine.

The bearing of these observations on the practical matter of interpreting various "phases" observed in seismograms after the first wave arrivals, whether from shots or earthquakes, is reasonably obvious. Observations where source and receiver are both deeply buried offer hope for observing vertical reflections and other low intensity returns.

It is a pleasure to acknowledge the stimulating discussions with Mr. Martin Greenspan, of the National Bureau of Standards, concerning the impedance matching of piezoelectric crystals.

References

[1] H. Nikano, Jap. J. Astr. Geophys., 2, 233-236 (1925).
[2] Lord Rayleigh, The theory of sound, 2, 145, London, Macmillan and Co. (1878).

FINAL RELATIVE SUNSPOT-NUMBERS FOR 1953

Table 1 contains the final sunspot-numbers for 1953 for the whole disk of the sun, based on observations made at the Zurich Observatory, supplemented by series furnished by other cooperating observatories. Table 2 gives the number of sunspot-groups on each day for the year 1953. The yearly mean of the group-numbers is 1.3 against 2.7 in 1952. The yearly mean of the relative numbers is 13.9 against 31.5 in 1952. One hundred and thirty-one (131) spotless days have occurred in 1953, against 23 in 1952. Therefore, sunspot-activity in 1953 was at a much lower

TABLE 1—*Final relative sunspot-numbers for the whole disk of the sun for 1953*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	16	0	0	43	46	15	0	0	7	7	12	0
2	15	7	0	49	40	28	7	7	0	0	11	0
3	20	8	0	50	35	23	7	12	7	7	10	0
4	24	8	0	57	26	51	0	12	7	7	9	0
5	24	8	14	35	9	35	0	11	7	7	0	0
6	35	10	0	35	8	32	7	10	14	13	0	0
7	34	14	7	38	8	36	7	16	9	13	0	9
8	45	8	0	43	0	30	0	12	24	14	0	0
9	50	14	0	30	0	28	9	29	23	12	0	0
10	55	13	0	21	0	26	18	48	28	10	0	0
11	59	13	0	12	0	18	20	73	28	9	0	0
12	59	7	0	0	0	8	16	77	30	14	0	0
13	60	0	7	0	0	7	23	73	18	14	0	0
14	62	0	15	0	0	13	24	65	29	29	0	0
15	60	0	8	0	0	24	38	62	41	23	0	0
16	46	0	7	0	7	33	20	54	42	17	0	0
17	37	0	0	0	8	33	17	47	38	9	0	0
18	30	0	8	7	14	20	21	31	38	0	0	0
19	25	0	10	7	10	25	11	26	34	0	0	0
20	17	0	8	0	10	26	8	24	21	0	7	0
21	14	0	10	0	11	22	14	17	25	7	0	7
22	18	0	10	9	11	20	0	15	16	0	0	0
23	8	0	10	27	11	12	0	8	9	0	0	0
24	8	0	9	33	13	12	0	0	15	7	0	8
25	0	0	9	45	18	15	0	0	18	0	0	9
26	0	0	7	57	11	20	0	0	21	12	0	9
27	0	0	17	66	10	21	0	0	7	9	0	11
28	0	0	25	63	18	7	0	0	8	7	0	10
29	0		32	57	24	8	0	0	7	0	0	9
30	0		47	49	20	7	0	0	7	0	0	7
31	0		50		19		0	0		7		0
Mean	26.5	3.9	10.0	27.8	12.5	21.8	8.6	23.5	19.3	8.2	1.6	2.5

level than in 1952. The general drop of solar activity continued through the whole year of 1953, ending with very small activity in November and December. Some reactivations of the sunspot-activity were observed in April, and again in June and August. It should be added that none of the observed spots occurred in high latitude and none belonged to the forthcoming solar cycle. It is true that a few short-lived very small spots at high latitudes with magnetic field-strength of less than 10 oersteds have been noticed during 1953, but as such features otherwise are not included in our statistics, for reasons of homogeneity, they should not be taken as spots. Therefore cycle No. 19 has not yet started and sunspot-minimum will prob-

Table 2—*Daily number of sunspot-groups for 1953*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	1	0	0	3	2	2	0	0	1	1	1	0
2	1	1	0	5	2	3	1	1	0	0	1	0
3	2	1	0	5	2	2	1	1	1	1	1	0
4	2	1	0	5	2	3	0	1	1	1	1	0
5	2	1	2	4	1	2	0	1	1	1	0	0
6	3	1	0	3	1	2	1	1	2	1	0	0
7	3	2	1	4	1	2	1	2	1	1	0	1
8	4	1	0	4	0	2	0	1	3	1	0	0
9	4	2	0	3	0	2	1	3	3	1	0	0
10	4	2	0	2	0	2	2	4	4	1	0	0
11	4	2	0	1	0	2	2	7	4	1	0	0
12	4	1	0	0	0	1	1	7	4	2	0	0
13	5	0	1	0	0	1	2	6	2	2	0	0
14	4	0	2	0	0	2	2	5	3	2	0	0
15	6	0	1	0	0	2	3	4	5	1	0	0
16	4	0	1	0	1	2	1	4	4	1	0	0
17	4	0	0	0	1	2	1	3	4	1	0	0
18	4	0	1	1	2	1	2	3	4	0	0	0
19	3	0	1	1	1	2	1	3	4	0	0	0
20	2	0	1	0	1	2	1	3	3	0	1	0
21	2	0	1	0	1	2	2	2	3	1	0	1
22	2	0	1	1	1	2	0	2	2	0	0	0
23	1	0	1	2	1	2	0	1	1	0	0	0
24	1	0	1	3	1	1	0	0	2	1	0	1
25	0	0	1	3	2	1	0	0	2	0	0	1
26	0	0	1	4	1	2	0	0	3	1	0	1
27	0	0	2	4	1	3	0	0	1	1	0	1
28	0	0	3	3	2	1	0	0	1	1	0	1
29	0		4	3	3	1	0	0	1	0	0	1
30	0		5	2	2	1	0	0	1	0	0	1
31	0		4		3		0	0		1		0
Mean	2.3	0.5	1.1	2.2	1.1	1.8	0.8	2.1	2.4	0.8	0.2	0.3

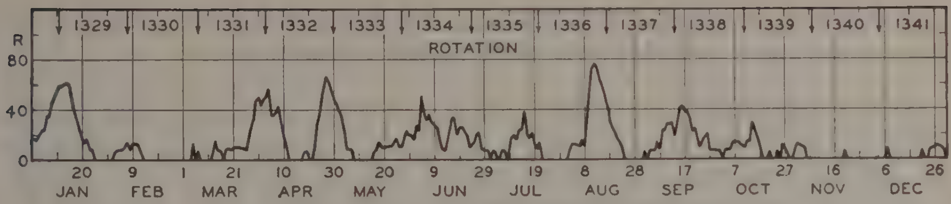

FIG. 1—DAILY RELATIVE SUNSPOT-NUMBERS FOR 1953

ably occur during 1954. Figure 1 gives a graphical representation of the daily relative sunspot-numbers for 1953, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are indicated by vertical arrows in the upper edge of Figure 1.

More details about the solar activity and the distribution and development of the individual spot-groups will be given in "Die Sonnenaktivität im Jahre 1953" (Astron. Mitt. der Eidgen. Sternwarte, Zürich, Nr. 186) and in "Heliographische Karten der Photosphäre für das Jahr 1953" (Publ. Eidgen. Sternwarte, Zürich, **10**, Fasc. 3).

M. Waldmeier

Swiss Federal Observatory
Zurich, Switzerland, February 26, 1954

INTERNATIONAL DATA ON MAGNETIC DISTURBANCES, FOURTH QUARTER, 1953

Preliminary Report on Sudden Commencements

S.c.'s given by five or more stations are in italics. Times given are mean values, with special weight on data from quick-run records.

Sudden commencements followed by a magnetic storm or a period of storminess (s.s.c.)

1953 October *15d 08h 45m:* twenty-nine.
1953 November *11d 13h 11m:* twenty.
1953 December: No s.s.c.

Sudden commencements of polar or pulsational disturbances (p.s.c.)

1953 October 01d 03h 18m: Fu SM Ta.—01d 12h 11: Ap Am.—*01d 18h 49:* ten.—03d 23h 45: CF Eb Tl Hr.—04d 10h 56: Ka Am.—04d 16h 21: SM El.—*04d 20h 27:* eight.—05d 23h 33: Eb Tl El.—*06d 18h 40:* six.—07d 20h 28: SM Eb Qu.—*08d 20h 59:* nineteen.—*09d 22h 36:* five.—10d 23h 06: Eb Tl SF El.—11d 17h 24: Fu SM.—*12d 18h 55:* eight.—16d 17h 34: Fu Ta El.—*16d 19h 40:* ten.—16d 23h 00: Fu Ta El Tn.—18d 02h 52: Te Ta.—20d 19h 20: Fu Ta.—22d 17h 16: Fu Tl.—22d 21h 10: Fu SM Ta Hr.—*24d 13h 01:* seven.—26d 18h 18: So Fu Qu Bi.

—*27d 00h 37:* ten.—*27d 18h 56:* eight.—27d 22h 21: Ma Fu SM Hr.—*28d 20h 48:* fifteen.—29d 19h 23: So Ta Tn Hr.—30d 19h 49: Tr So Fu.

1953 November *01d 18h 05m:* seventeen.—*04d 22h 00:* five.—06d 13h 29: Ka Qu To Am.—*07d 20h 20:* eight.—08d 11h 11: Ka To Am.—*08d 23h 05:* eighteen.—09d 22h 32: Le Es MB.—10d 19h 04: Qu Tn.—10d 19h 57: Qu Tn.—11d 14h 04: Qu El.—11d 17h 51: CF Qu.—15d 04h 20: CF SM.—15d 18h 08: Fu Qu.—15d 18h 26: El Tn.—16d 01h 03: CF Eb Tl Hr.—*16d 02h 20:* six.—16d 17h 32: Fu Ci.—16d 22h 03: CF MB.—16d 22h 30: Fu El.—17d 01h 23: Fu SM.—*19d 19h 55:* eight.—20d 18h 12: Wm Fu.—20d 20h 40: Fu SM MB.—*21d 18h 23:* six.—21d 18h 57: Ma Eb.—*23d 20h 11:* ten.—23d 23h 48: Fu SF.—25d 23h 16: CF SF.—30d 18h 50: Qu Hr.

1953 December 02d 18h 52m: Tr Qu.—*03d 02h 14:* ten.—*03d 23h 52:* nineteen.—04d 17h 32: Fu Qu.—05d 17h 18: Fu IK Qu.—*07d 01h 50:* six.—07d 22h 06: Fu Eb.—08d 19h 42: Eb Qu.—08d 23h 09: Fu Eb Bi.—09d 19h 21: Wn Fu Tl Hr.—*09d 19h 47:* seven.—11d 20h 11: El Hr.—12d 15h 08: Ka Bi.—12d 23h 00: CF SM SF.—13d 18h 37: Tr So Qu.—*13d 19h 45:* fifteen.—14d 16h 50: So Qu.—15d 19h 43: IK Hr.—17d 16h 07: Fu IK Ka Qu.—17d 17h 15: Wn Fu IK Qu.—17d 20h 47: Tr So Wn Fu.—17d 21h 54: SM Qu.—18d 17h 09: IK Qu.—*21d 22h 54:* thirteen.—*22d 19h 03:* eleven.—23d 18h 04: Wn Fu IK Qu.—25d 22h 06: Do Fu SM.—26d 19h 40: CF Qu.—27d 20h 38: Tr CF Fu.—*27d 21h 22:* five.—*29d 00h 05:* six.

Sudden impulses found in the magnetograms (s.i.)

1953 October *07d 00h 00m:* eleven.—07d 07h 20: Ta SM.—11d 10h 52: Te Ta Hr.—15d 13h 04: Ta Tn.—15d 13h 29: CF SM Ta.—15d 13h 37: Ta Tn.—15d 14h 14: Ta MB.—16d 01h 54: Ta Tn.—18d 18h 44: Fu Ta.

1953 November 12d 22h 32m: Tn Am.—17d 11h 40: So Tn.—23d 08h 50: SM Bi.—23d 15h 54: Ka Tn.—23d 17h 40: Ka Tn.—23d 17h 48: Ka Tn.

1953 December 11d 17h 46m: Ci El.—29d 15h 15: Wn Ma.—29d 17h 00: Qu Hu.

Preliminary Report on Solar-flare Effects

Effects confirmed by ionospheric or solar observations are in italics.

1953 October 06d 20h 33m–20h 45m: Te.—06d 21h 15–21h 21: Te.—07d 14h 16–14h 29: Te.—*14d 07h 44:* CF.—*14d 08h 11:* CF.—*14d 09h 50–10h 15:* Wi CF Eb Tl MB Bi El Hr Tn.—*14d 14h 23–14h 40:* CF Ch Tl MB Hu Hr SM.—14d 23h 45–24h 00: Ka.—16d 10h 03–10h 10: SM.—24d 13h 05: Bi.—25d 19h 18–21h 38: Ch.—25d 19h 20–19h 28: Te.—25d 20h 11–20h 20: Te.—25d 20h 38–20h 47: Te.—25d 21h 27–21h 39: Te.—25d 22h 17–22h 27: Tu.—25d 23h 08–23h 16: Tu.—25d 23h 34–23h 46: Tu.—26d 00h 24–00h 36: Tu.—26d 12h 15–12h 20: Hr.—29d 17h 09–17h 24: Te Va.—30d 19h 01–19h 18: Te Hu.—31d 12h 50–12h 58: SM.

1953 November 09d 07h 36m–07h 45m: Hr.—16d 11h 50–11h 55: SM.—16d 18h 29–18h 35: Te.—16d 19h 17–19h 24: Te.—24d 13h 12–13h 19: Te.—24d 20h 35–20h 41: Te.—26d 14h 50: Hu.

Geomagnetic planetary three-hour-range indices Kp, preliminary magnetic character-figures, C, and final selected days, October to December, 1953

E	October 1953								
	1	2	3	4	5	6	7	8	Sum
1	3o	5 −	2 +	2 −	3 +	2 −	3o	1 +	21o
2	2 −	1 +	1 −	2 −	2 −	2 +	2 −	1o	12o
3	1 −	3 −	2 −	2 +	2o	2 −	1o	2 −	14 −
4	2o	1o	0 +	1 +	1o	1o	2 −	1 +	10 −
5	1 −	1 +	1 +	2 −	0 +	0 +	1o	1 −	7 +
6	2 −	1o	2 −	1o	1 +	1 −	1 +	1o	10 −
7	2o	1 −	5 −	3o	3 +	1 +	0 +	3 −	18o
8	2 −	2 +	3 −	2 +	2o	2 −	2 −	4o	18 +
9	2o	3 +	3 +	2 +	1 +	1 +	1 +	2o	17o
10	3o	2o	1o	1 −	2 −	3 −	4 −	3 −	17 +
11	1 −	1o	1 −	2 −	3o	3 +	2 +	1o	14 −
12	1 −	1o	1 −	1o	1 −	0 +	2o	1 +	8 −
13	1 −	1o	0 +	1 +	1 −	2 −	1 +	2 −	9 −
14	1 −	2o	1o	0 +	0 +	1 −	0 +	0o	5 +
15	0o	0o	2o	2 −	6o	7 +	6 −	5 +	28o
16	6o	5 −	4o	2 +	3 −	5 −	6 −	6o	36o
17	5 −	4 −	4 +	4 +	4 −	5 +	4 +	4o	34 +
18	4 +	5 −	5o	4 +	5 +	6o	5 +	5 +	40 +
19	6 +	5 +	6 −	6o	5 +	5 −	4 +	4 −	41 +
20	4 +	5 +	5 −	4o	5 −	5 −	5 −	5 −	37o
21	3 +	3o	5 +	6 −	4 +	3 −	1 +	2o	28 −
22	2 −	4 +	5 −	3 +	3o	4o	3o	2 +	26 +
23	3o	4o	3 +	3 −	2 +	3 −	2o	1o	21o
24	0 +	0 +	2 +	3 −	5 −	2 +	1o	1 +	15o
25	3 −	4 −	2o	2 +	2 −	1o	2 −	2o	17o
26	1 +	2 −	2 +	2o	0 +	0 +	2 −	1 +	11o
27	4 −	3o	4 +	3o	2 +	3 −	4 −	3 −	25 +
28	3 +	2 +	1o	1 +	0 +	2 −	2o	2o	14o
29	2 +	3o	2 −	1 +	2o	3 −	3o	4o	20o
30	3o	2 −	2 −	2o	1 +	1o	2o	1o	14 −
31	3 +	3o	3o	1 −	1o	1o	0o	0 +	12 +

E	November 1953								
	1	2	3	4	5	6	7	8	Sum
1	0 +	0 +	1o	2o	1 −	1o	2 +	2 −	9 +
2	1 −	0 +	2o	1 +	1 −	1 +	1 −	1o	8o
3	1o	1 −	1o	1o	2 −	2o	2o	2 −	11o
4	2 +	1 +	1 +	1 +	1 −	0 +	0 +	2 −	9 +
5	2 +	4 −	3 +	3o	4o	3 −	2o	0o	21o
6	1 +	1 −	3 −	2o	3o	2 −	1 −	1 −	13 −
7	0 +	2o	2 −	2 −	1o	1o	2 −	1o	10 +
8	0 +	0 +	2 −	1 +	1 +	1 +	1 −	2o	9o
9	2 +	2o	1 +	1 −	0o	0o	0o	1 −	7o
10	0o	0o	0 +	0 +	0 +	0o	1 −	0 +	2o
11	0o	0o	0 +	1 −	2o	1 +	2 +	2o	9 −
12	3 +	1 +	2 −	2 +	4 −	3 −	4o	4 +	23 +
13	4 +	6 −	5 −	4 +	6 −	4 +	5 −	4 +	38o
14	3o	5 +	4 −	3 +	5 +	5 −	4 +	4o	34 −
15	2o	4o	5o	5o	5o	5 −	5o	2 −	34 −
16	5o	6 −	4o	3o	3o	4 +	4 +	4 −	33o
17	4 −	3o	3 −	3o	3o	4o	3 +	4 +	27o
18	3 +	4o	3o	4o	3o	3 −	2 +	3 −	25o
19	4 +	5 −	4 −	4 −	5 +	3 +	5 −	5 −	34 +
20	4o	4 +	4 +	3 +	3o	4 −	4o	4 +	31o
21	3 +	2 +	3 −	4 −	3o	1o	2 +	2o	20 +
22	2 −	1 −	2o	1o	2o	1 −	2 −	2 −	11 +
23	1 +	2 −	4 −	4o	3 +	4 −	5o	4o	27 −
24	4o	4 −	4 −	3 −	1o	2 +	2 −	2 +	21 +
25	2o	4o	3 −	2o	3 −	2o	3o	4 −	22o
26	4 −	2 +	2 −	1o	1 −	1 −	1o	1o	12o
27	2 +	1 +	4 −	2 −	2 +	2 −	1 +	2o	16 +
28	1 −	1 +	0 +	1 −	0o	0o	0 +	1 +	5 −
29	3 −	2 +	1 +	2 −	0 +	0o	0o	0 +	9 −
30	1o	0o	1 −	1 −	1 −	1o	1o	1 −	6 −
31									

E	December 1953								
	1	2	3	4	5	6	7	8	Sum
1	0 +	1 −	1 −	0 +	0 +	0 +	1 −	1 −	4o
2	1 +	1 −	2o	1 −	0 +	1 −	1o	0 +	7o
3	2 −	2 −	1 −	1 +	1 +	1o	1o	2o	11 −
4	4o	2 −	2 −	1 +	1 −	1o	2o	2o	14 +
5	3 −	2o	1o	1o	0 +	1 +	1o	0o	9 +
6	1 +	0 +	1 −	1o	3 −	2 +	2 −	2o	12o
7	3o	2o	1 +	2 −	0 +	0 +	0 +	2o	11o
8	1 −	2 −	2 −	1o	1 +	2o	2o	3 −	13o
9	3 +	1 −	1 −	1 −	1o	2o	3 +	2 −	13 +
10	1 +	0o	1 +	2o	1o	2o	0 +	2 −	10 −
11	2o	4o	3 −	4 +	5o	4 −	4 −	4 +	30 −
12	4 +	3 +	4o	2o	3 +	4 −	3 −	4 −	27o
13	2 +	3 −	2 −	2 −	2o	1 +	4 −	2 +	18 −
14	1o	1 +	2 −	1 +	1 +	1 +	2o	1 +	11 +
15	0 +	1o	1 +	2o	1o	1 −	3o	2 +	12 −
16	2 −	1 −	2o	2o	1 −	1o	1 −	2 −	10 +
17	2 −	2 −	1o	1o	1 +	2o	1o	3o	13 −
18	3o	0 +	1o	1o	2 −	2 −	2 −	2 −	12o
19	1o	0 +	2 −	1 −	1o	2o	2o	2 −	10 +
20	1o	1 +	1 +	0 +	1 +	3 −	2o	1 +	11 +
21	2o	1 +	1o	1 −	1 −	0 +	0 +	3 −	9o
22	2 −	3 −	2 +	1 +	2 −	2 +	3o	1 +	16 +
23	1 −	0 +	1 −	0 +	2 −	1 +	2 +	2 −	9o
24	2 +	2 +	2 +	2 −	0 +	0o	1o	1o	11o
25	1 +	1o	2o	1o	1o	2o	1 +	3o	13 −
26	1 +	0 +	0o	1o	1o	1 +	2 −	3 −	9 +
27	1 +	1o	2 −	2 −	2 −	2 −	2o	4 −	15 −
28	3o	2o	1o	2 −	2 +	2o	2 −	1 +	15o
29	3 −	1 −	1o	1 +	2o	3 −	2 −	3o	15o
30	1o	2 −	1 +	1 +	1 +	1o	1 +	1 +	10 +
31	1 −	1o	2o	2 −	0 +	0 +	0 +	1 −	7o

E	Preliminary C. 1953		
	Oct.	Nov.	Dec.
1	0.8	0.4	0.0
2	0.4	0.0	0.0
3	0.3	0.2	0.2
4	0.2	0.1	0.6
5	0.0	0.8	0.3
6	0.2	0.3	0.4
7	0.7	0.2	0.2
8	0.7	0.3	0.4
9	0.5	0.0	0.6
10	0.6	0.0	0 3
11	0.5	0.4	1.3
12	0.2	1.1	1.0
13	0.1	1.6	0.7
14	0.0	1.5	0.2
15	1 6	1.6	0.4
16	1.6	1.4	0.2
17	1.4	1.1	0.4
18	1.5	0.9	0.2
19	1.6	1.5	0.3
20	1.4	1.2	0.3
21	1.0	0.7	0.3
22	0.9	0.1	0.7
23	0.6	1.3	0.3
24	0.7	0.7	0.2
25	0.3	0.7	0.3
26	0.1	0.2	0.3
27	0.8	0.3	0.6
28	0.4	0.0	0.4
29	0.6	0.1	0.6
30	0.3	0.0	0.2
31	0.2		0.1

Final selected days		
Oct.	Nov.	Dec.
Five quiet		
5	2	1
6	9	2
12	10	23
13	28	30
14	30	31
Five disturbed		
15	13	11
16	14	12
18	15	13
19	16	22
20	19	29
Ten quiet		
2	1	1
3	2	2
4	4	3
5	7	10
6	8	16
12	9	21
13	10	23
14	11	26
26	28	30
30	30	31

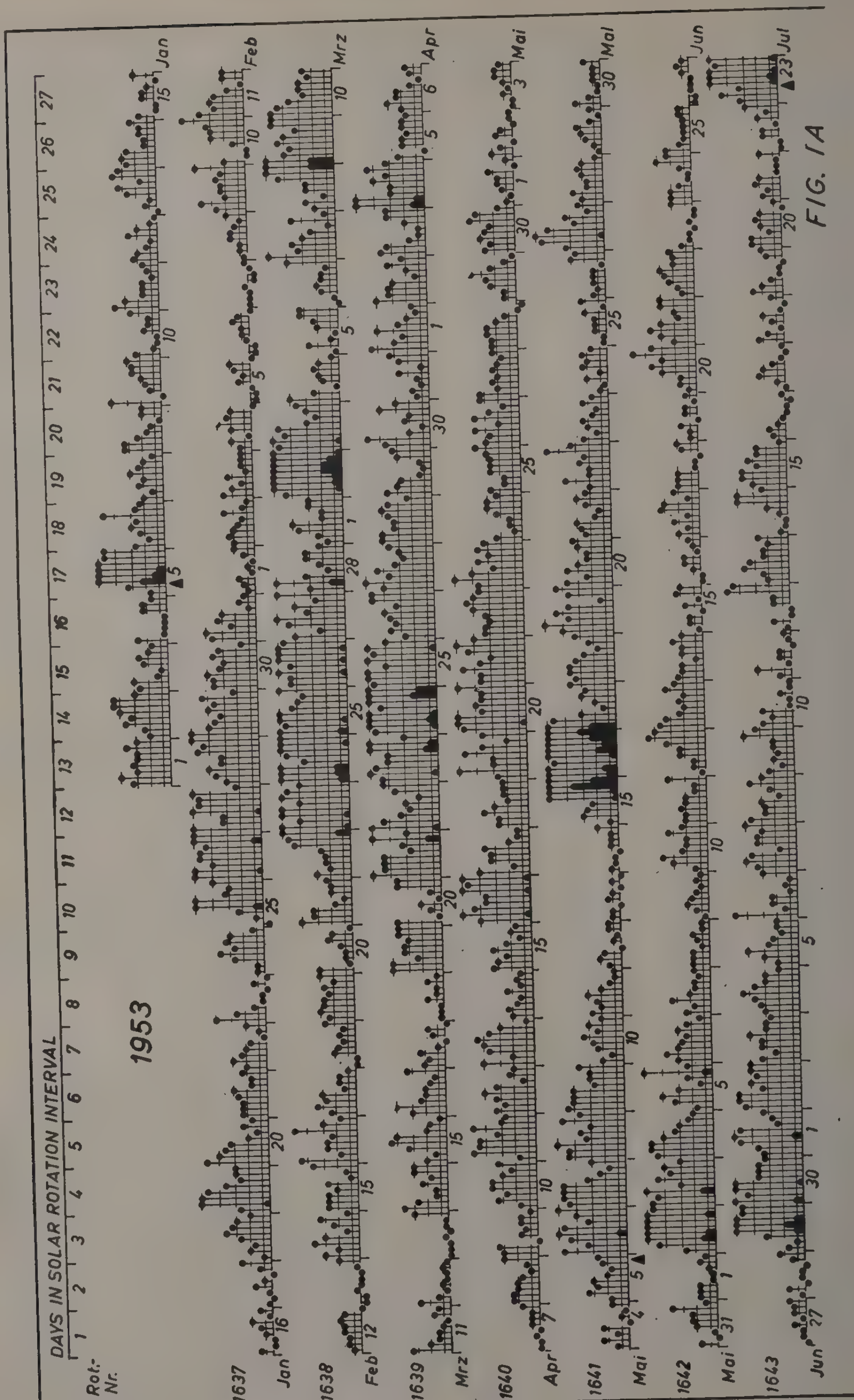
DAYS IN SOLAR ROTATION INTERVAL
Rot.-Nr.
1953
1637
1638
1639
1640
1641
1642
1643

FIG. 1A

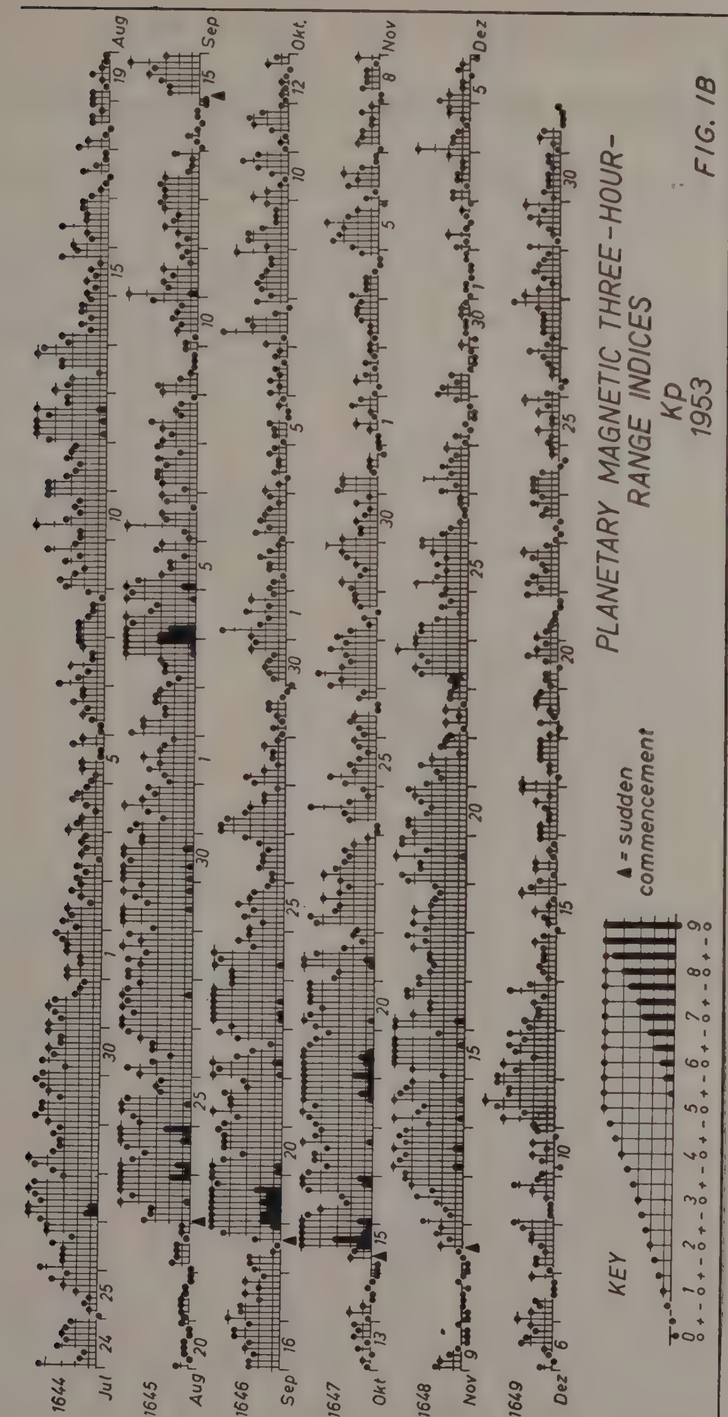

FIG. 1B
PLANETARY MAGNETIC THREE-HOUR-RANGE INDICES
Kp
1953

1953 December 26d 02h 55m–03h 12m: Ka.—27d 09h 10: Bi.—27d 10h 05: El.—30d 11h 37: Bi.—31d 09h 55: El.

Ionospheric or solar disturbances without clear geomagnetic effect

None.

Minor disturbances reported by one station only are listed in the De Bilt quarterly circular, but omitted here.

Committee on Characterization of Magnetic Disturbances

J. Bartels, *Chairman*
University
Göttingen, Germany

J. Veldkamp
Kon. Nederlandsch Meteorologisch Instituut
De Bilt, Holland

PROVISIONAL SUNSPOT-NUMBERS FOR JANUARY TO MARCH, 1954

(Dependent on observations at Zurich Observatory and its station at Locarno and Arosa)

Day	Jan.	Feb.	Mar.
1	0	0	8
2	0	0	11
3	0	0	9
4	0	0	7
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	8
13	0	0	17
14	0	0	22
15	0	0	36
16	0	0	40
17	0	0	42
18	0	0	39
19	0	0	29
20	0	0	23
21	0	0	17
22	0	0	12
23	0	0	7
24	0	0	7
25	0	0	0
26	0	0	0
27	0	0	0
28	0	7	0
29	0		0
30	0		0
31	0		0
Means........	0.0	0.2	10.8
No. days......	31	28	31

Mean for quarter: 3.8 (90 days)

M. WALDMEIER

SWISS FEDERAL OBSERVATORY
Zurich, Switzerland

CHELTENHAM THREE-HOUR-RANGE INDICES K FOR JANUARY TO MARCH, 1954

[$K9 = 500\gamma$; scale-values of variometers in γ/mm: $D = 5.4$; $H = 2.5$; $Z = 4.3$]

Gr. day	January 1954 Values K	Sum	February 1954 Values K	Sum	March 1954 Values K	Sum
1	2121 1121	11	1443 2343	24	1221 0124	13
2	3233 5432	25	4332 3223	22	4433 1123	21
3	2223 2112	15	3245 2223	23	4310 2132	16
4	0000 0010	1	3342 1111	16	2233 2223	19
5	1000 1134	10	0122 0112	9	4232 2123	19
6	2322 2211	15	1221 0000	6	3312 2222	17
7	1210 1121	9	0110 0122	7	4424 2233	24
8	3332 1123	18	3211 2022	13	3333 2234	23
9	2122 2222	15	1122 2221	13	3323 1442	22
10	1222 1122	13	2222 3022	15	0133 2223	16
11	0322 1112	12	4222 2134	20	4343 3333	26
12	1122 2322	15	3021 1122	12	2332 3223	20
13	3342 2112	18	2123 1112	13	2212 2333	18
14	1111 1123	11	0012 2232	12	4543 4435	32
15	3132 2223	18	1335 5533	28	5454 3334	31
16	2212 2131	14	4422 3444	27	3333 3232	22
17	0110 1222	9	5523 4333	28	3322 2444	24
18	3222 2235	21	3333 2332	22	5432 2232	23
19	4244 2234	25	1242 2232	18	3222 4233	21
20	4243 3242	24	3322 2231	18	4344 2335	28
21	4422 2233	22	2224 4445	27	4223 1232	19
22	3433 2131	20	6533 3335	31	4222 1254	22
23	4443 2222	23	4444 2334	28	5344 3346	32
24	3221 1111	12	3133 3223	20	4443 2344	28
25	2111 1221	11	3213 1133	17	4242 2232	21
26	3100 0012	7	3335 3344	28	3444 3333	27
27	1111 2121	10	3344 3525	29	4322 1122	17
28	1132 0001	8	5222 2223	20	3232 0122	15
29	1221 1111	10			3111 2223	15
30	1111 0112	8			4222 4234	23
31	2312 1222	15			3332 2222	19

J. B. CAMPBELL
Observer-in-Charge

CHELTENHAM MAGNETIC OBSERVATORY
Cheltenham, Maryland, U.S.A.

PRINCIPAL MAGNETIC STORMS

(Advance knowledge of the character of the records at some observatories as regards disturbances)

Observatory (Observer-in-Charge)	Greenwich date	Storm-time: GMT of begin.	Storm-time: GMT of ending[1]	Sudden commencement: Type[2]	Amplitudes[3] D	Amplitudes[3] H	Amplitudes[3] Z	C-figure, degree of activity[4]	Maximal activity on K-scale 0 to 9: Gr. day	Gr. 3-hr. period	K-index	Ranges D	Ranges H
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	1954	h m	d h		′	γ	γ					′	γ
College	Jan.	None											
(C. J. Beers)	Feb. 1	03 30	1 09	...	...	...	...	ms	1	3,4,5,6	5	100	1060
	Feb. 15	10 20	17 23	...	...	...	...	s	15	6	8	220	2860
	Feb. 21	06 00	24 01	...	...	...	...	ms	21	5	7	190	1560
	Feb. 26	06 30	28 19	...	...	...	...	ms	26	4	7	260	1250
									27	6	7		
	Mar. 13	12 30	16 17	...	...	...	...	ms	14	6	7	190	1520
Sitka	Jan.	None											
(T. L. Skillman)	Feb. 15	05 15	17 18	...	...	...	...	ms	15	6	7	69	530
	Feb. 21	09 14	24 01	...	...	...	...	m	21	6,7,8	5	62	412
									22	1,2,3,4,5	5		
									23	6	5		
	Feb. 26	07 00	28 02	...	...	...	...	m	26	4	6	58	400
	Mar. 13	12 29	16 15	...	...	...	...	ms	14	3	7	83	528
	Mar. 22	17 17	24 11	...	...	...	...	m	22	7,8	5	50	343
									23	3,4,5	5		
									24	3	5		
	1953												
Witteveen	Oct. 15	08 45	21 16	s.c.	−1	+7	0	ms	15	6	7	65	230
(D. van Sabben)	Nov. 12	13 00	20 24	...	...	...	...	ms	14	6	6	50	240
									15	6,7	6		
									19	7	6		
	Nov. 23	07 00	24 07	...	...	...	...	ms	23	7	6	25	180
	Dec. 11	05 00	12 24	...	...	...	...	m	11	8	5	25	125
									12	6	5		
	1954												
Cheltenham	Jan. 1	18 ..	2 22	...	...	...	...	m	2	5	5	16	87
(Joel B.	Jan. 18	20 ..	23 12	...	...	...	...	m	18	8	5	21	80
Campbell)	Feb. 1	02 ..	4 08	...	...	...	...	m	3	4	5	22	64
	Feb. 15	05 ..	20 03	...	...	...	...	m	15	4,5,6	5	27	118
									17	1,2	5		
	Feb. 21	10 ..	25 06	...	...	...	...	ms	22	1	6	46	125
	Feb. 26	06 ..	28 03	...	...	...	...	m	26	4	5	27	103
									27	6,8	5		
									28	1	5		
	Mar. 10	19 ..	12 24	(Moderately disturbed period)									
	Mar. 13	19 ..	19 03	...	...	...	...	m	14	2,8	5	30	125
									15	1,3	5		
									18	1	5		
	Mar. 22	17 17	27 04	s.c.	−1	3	...	ms	23	8	6	29	106
San Juan	Jan.	None											
(P. G. Ledig)	Feb. 21	10 35	22 05	s.c.	0	+3	−1	m	21	6,8	5	10	138
									22	1,2	5		
	Mar.	None											
Honolulu	Jan.	None											
(R. F. White)	Feb. 21	10 00	24 01	...	...	...	...	m	21	8	5	5	94
	Mar. 22	17 17	24 12	...	...	...	...	m	23	8	5	8	95

[1]Approximate time of ending of storm construed as the time of cessation of reasonably marked disturbance movements in traces; more specifically, when the K-index measure diminished to 2 or less for a reasonable period.

[2]s.c. = sudden commencement; s.c.* = small initial impulse followed by main impulse (the amplitude in this case is that of *main impulse only*, neglecting the initial brief pulse; ... = gradual commencement.

[3]Signs of amplitudes of D and Z taken algebraically; D reckoned positive if towards the east and Z reckoned positive if v cally downwards.

[4]Storm described by three degrees of activity: *m* for moderate (when K-index as great as 5); *ms* for moderately severe (w K = 6 or 7); *s* for severe (when K = 8 or 9).

PRINCIPAL MAGNETIC STORMS—*Concluded*

bservatory (Observer-n-Charge)	Green-wich date	Storm-time		Sudden commencement				C-figure, degree of activity[4]	Maximal activity on K-scale 0 to 9			Ranges		
		GMT of begin.	GMT of ending[1]	Type[2]	Amplitudes[3]				Gr. day	Gr. 3-hr. period	K-index	D	H	Z
					D	H	Z							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	1954	h m	d h		′	γ	γ					′	γ	γ
tituto	Jan. 1	17 38	2 22	.....	....	....	....	m	2	6,7	5	5	158	34
ofísico de	Jan. 31	03 58	2 18	.....	....	....	....	m	1	6,7	5	4	163	26
ancayo	Feb. 15	05 10	17 22	.....	....	....	....	m	16	6	5	5	222	26
A. Giesecke)	Feb. 21	12 22	23 23	.....	....	....	....	m	21	5,6,7	5	7	310	26
	Feb. 26	06 40	27 22	.....	....	....	....	m	26	5,6	5	6	204	19
	Mar. 13	11 05	16 05	.....	....	....	....	m	14	6	5	5	164	31
	Mar. 22	17 17	25 05	s.c.	0	27	5	m	22	7,8	5	4	261	32
	1953													
ssouras	Oct. 15	08 45	17 04	s.c.	−1	+20	?	ms	15	6	7	10	235	34
lio I. Gama)	Nov. 23	09 00	24 11	.....	....	....	....	m	23	6	5	11	127	22
	Dec.	None												
	1954													
ia	Jan. 18	19 ..	23 15	.....	....	....	....	m	19	7	5	8	88	21
G. Gill)	Feb. 25	23 00	28 15	s.c.	0	+8	−2	m	27	3	5	4	52	19
	Mar. 22	17 20	26 +	s.c.	0	+8	−2	m	22	7	5	6	93	22
									23	3,8	5			
rmanus	Jan. 2	01 17	2 23	s.c.	....	....	....	m	2	5	5	16	89	59
M.	Jan. 19	05 ..	20 04	.....	....	....	....	m	19	6,8	5	17	41	58
van Wijk)	Feb. 15	03 ..	16 07	.....	....	....	....	m	15	4,6	5	10	116	89
	Feb. 21	10 ..	22 15	.....	....	....	....	ms	21	6,7	6	22	106	136
	Feb. 26	06 ..	27 02	.....	....	....	....	m	26	4,6	5	18	69	59
	Mar. 13	11 ..	15 23	.....	....	....	....	m	14	6	5	18	81	93
	Mar. 22	17 16	24 12	s.c.	0	+2	+2	m	22	7,8	5	22	76	92
									23	7,8	5			
	Mar. 30	08 ..	31 00	.....	....	....	....	m	30	5,8	5	8	80	73
	1953													
za	Oct. 15	08 47	16 24	s.c.	+1	+27	−1	m	15	5,6	...	5	272	19
Leroy)	Nov.	None												
	Dec.	None												
	1954													
olangi	Jan. 1	21 ..	3 01	.....	....	....	....	m	2	5	5	21	122	41
B. Tenni)	Jan. 18	21 ..	23 12	.....	....	....	....	m	18	8	5	17	121	26
									19	7	5			
	Feb. 15	02 ..	17 22	.....	....	....	....	ms	15	5,6	6	26	169	48
	Feb. 21	10 ..	28 18	.....	....	....	....	m	21	7	5	22	147	65
									22	5	5			
									23	6	5			
									26	4	5			
									27	3,6	5			
	Mar. 13	11 30	18 21	.....	....	....	....	m	14	6	5	18	117	41
									15	3	5			
	Mar. 20	00 ..	27 03	.....	....	....	....	m	22	7,8	5	23	168	42
									23	5,7,8	5			
									26	5	5			
	1953													
nberley	Oct. 15	08 43	21 18	s.c.*	0	+8	−2	ms	15	6	6	27	217	116
. F. Baird)	Oct. 27	06 ..	27 10	.....	....	....	....	m	27	3	5	9	83	21
	Nov. 12	22 32	16 12	s.c.*	+1	+12	−5	m	13	2,3,5	5	21	123	47
	Dec. 11	03 ..	12 18	.....	....	....	....	m	11	5	5	17	158	45
	1954													
. L.	Jan.	None												
Cullington)	Feb. 15	04 ..	16 06	.....	....	....	....	m	15	5	5	19	129	48
	Feb. 16	19 ..	18 00	.....	....	....	....	m	17	4	5	15	122	53
	Feb. 26	06 ..	28 03	.....	....	....	....	m	26	4	5	22	121	46
									27	6	5			
	Mar. 13	12 30	16 15	.....	....	....	....	m	14	3	5	17	97	46
									15	3	5			
	Mar. 22	17 16	25 12	s.c.	+1	+12	−4	m	22	7,8	5	20	146	43
									23	3,5,8	5			
									24	3	5			

LETTERS TO EDITOR

LONG-RANGE RADIO ECHOES FROM AURORAL IONIZATION

Radio echoes believed to be from auroral ionization are consistently observed at the relatively low geomagnetic latitude (43°.75) of Stanford University. Previous radio observations[1,2,3,4,5,6,7,8] have been made at much higher geomagnetic latitudes (53° to 67°). These echoes are unusual for several reasons. First, the ranges at which they are observed (1,600 to 4,700 km) are much greater than ranges previously reported. Second, the observation frequencies of 6.425 Mc, 12.8625 Mc, and 17.31 Mc are lower than those previously used for auroral work. Third, the height above the earth at which reflection is believed to take place is greater than the height at which auroral reflections are commonly thought to occur. Fourth, the strength of the echoes is surprisingly great, being frequently greater than the strongest *F*-layer propagated ground-scatter echoes occurring at the same time.

At Stanford, the reflections were first detected in October 1952, during investigations of sporadic-*E* ionization by means of the scatter-sounding technique.[9,10] Auroral echoes are readily distinguishable from ground-scatter echoes by consideration of their bearing, echo shape, amplitude fluctuation, Doppler shift, and time of occurrence. The bearings of the echoes correspond closely to geomagnetic north, although some are detected in directions as much as 30° east and 30° west of that direction.

The echoes seen may be divided into two types: discrete and diffuse. The discrete echo, which is the most striking, is of very large amplitude and has a shape matching that of the 1,500-μsec transmitted pulse. The diffuse echo has a width

[1]D. Davidson, Reflexion of high frequencies during auroral activity, Nature, **167**, 277-278 (1951).

[2]A. C. B. Lovell, J. A. Clegg, and C. D. Ellyett, Radio echoes from the Aurora Borealis, Nature, **160**, 372 (1947).

[3]A. Aspinall and G. S. Hawkins, Radio echo reflections from the aurora borealis, J. Brit. Astr. Assoc., **60**, 130-135 (1950).

[4]P. A. Forsyth, W. Petrie, F. Vawter, and B. W. Currie, Radio reflexions from auroras, Nature, **165**, 561-562 (1950).

[5]G. Hellgren and J. Meos, Localization of aurora with 10 M high power radar technique using a rotating antenna, Res. Lab. Electronics, Chalmers Univ., Rep. No. 26 (1952).

[6]D. W. R. McKinley and P. M. Millman, Long duration echoes from aurora, meteors, and ionospheric back-scatter, Can. J. Phys., **31**, 171-181 (1953).

[7]L. Harang and B. Landmark, Radio echoes observed during aurorae and terrestrial magnetic storms using 35 and 74 Mc/s waves simultaneously, Nature, **171**, 1017-1018 (1953).

[8]R. K. Moore, A V.H.F. propagation phenomenon associated with aurora, J. Geophys. Res., **56**, 97-106 (1951).

[9]A. M. Peterson, The mechanism of *F*-layer propagated back-scatter echoes, J. Geophys. Res., **56**, 221-237 (1951).

[10]A. M. Peterson, A scatter sounder for the study of sporadic ionization in the upper atmosphere, Radio Propagation Lab., Stanford University, Contract DA-04-200-ORD-181, Tech. Rep. No. 1 (Sept. 1953).

several times that of the transmitted pulse, and is much smaller in amplitude than the discrete type. Discrete echoes tend to appear very suddenly at almost maximum amplitude for that particular occurrence. They remain for an interval varying between a few seconds and many minutes, and then suddenly disappear. Diffuse echoes are quite irregular in their behavior. Both the discrete and the diffuse auroral echoes are characterized by rapid amplitude variations and large Doppler shifts. "A-scope" displays of discrete and diffuse echoes, with phase coherent outputs to illustrate Doppler shifts, are shown in Figure 1.

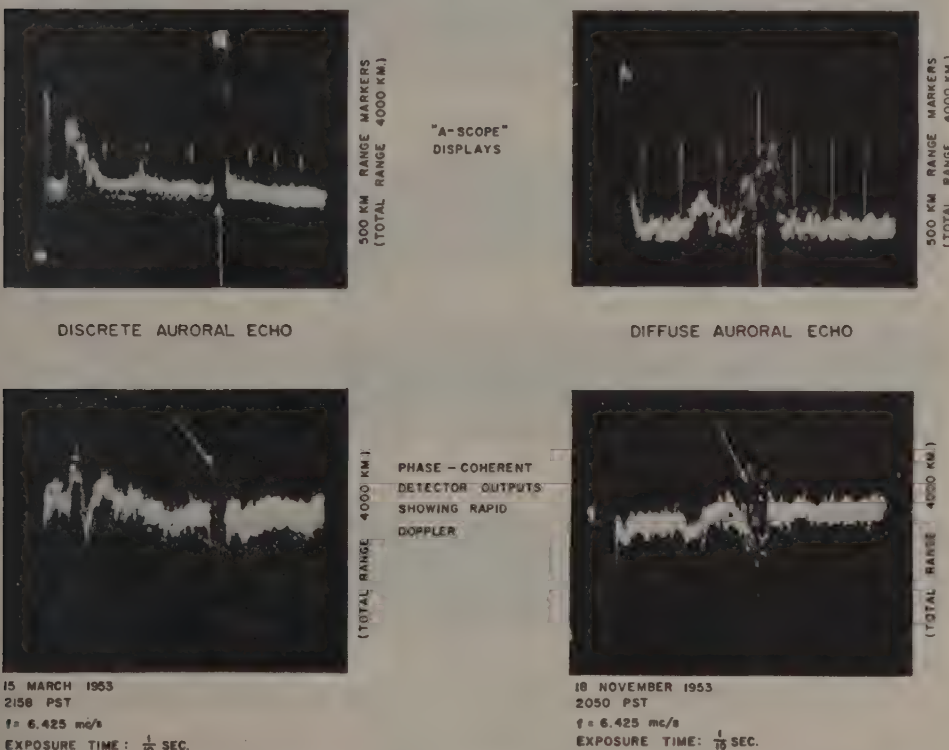

Fig. 1—"A-scope" and Doppler displays of discrete and diffuse auroral echoes on 6.425 Mc/s

Closely spaced groups of echoes are frequently observed on 6 and 17 Mc. Range differences of about 200 km between the echoes are common. Examples of such echoes on 6 Mc are shown in Figure 2.

On several occasions, echoes have been observed simultaneously on two frequencies at the same range. One instance of this was on 3 April 1953, when echoes were seen at 1,600 km on 6 and 17 Mc.

The seasonal and diurnal variation of the number of echoes and their duration are in accordance with the variation of visual auroras. A correlation of magnetic activity (K-index) and radio echo-occurrence frequency indicates a close relationship between the two (correlation coefficient = 0.85). The sudden appearance and disappearance of these echoes are typical of the behavior of visual auroras. Multiple

radio echoes might be explained as reflections from several auroral curtains at different geomagnetic latitudes.

The shape and relatively great amplitude of the discrete auroral echo suggest reflection from a moderately large surface having a relatively small depth in range. It is believed that the observed echoes are the result of perpendicular reflection from sheets of auroral ionization formed parallel to the earth's magnetic field lines.

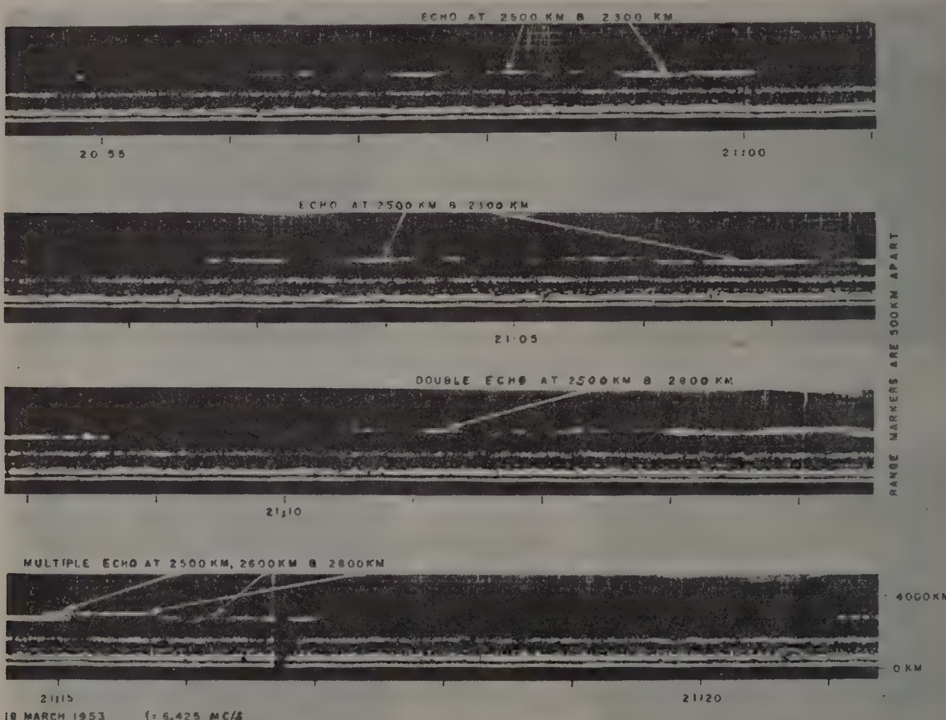

FIG. 2—Range-time display of auroral echoes on 6.425 Mc/s. Note multiple echoes.

The shorter-range echoes (roughly 1,600-km slant range) are believed to be caused by energy traveling in a straight line from the transmitter to the point of reflection. At this range from Stanford, and in the direction in which the echoes are observed, an outgoing ray would intersect a magnetic field line at perpendicular incidence at a height of 300 km. In the case of the longer-range echoes, the outward-going ray must be bent downward by the *F*-layer. If bending is assumed, consideration of geometrical relationships shows that the perpendicular-incidence requirement will still be satisfied at approximately the same height above ground.

The importance of the *F*-layer in the production of these echoes is suggested by the fact that the echoes are present on 17 Mc only when the *F*-layer is capable, or nearly so, of reflecting the energy back to earth. This condition is nearly always satisfied on 6 Mc/s, and the echoes are observed on this frequency at all times of the day. On 30.66 Mc, the *F*-layer to the north of Stanford is rarely capable of deviating the wave appreciably, and auroral echoes have not been observed. Though a variety

of modes of propagation (other than the F-layer-deviated one) can be postulated, none are satisfactory to explain all of the observations. Objection to the F-layer-deviated path may be made on the grounds that a large amount of defocusing can be expected to take place under the conditions which produce the required amount of deviation.

The experimental evidence to date makes the possibility that echoes originate at E-layer heights very unlikely, and suggests that the reflections occur at heights considerably in excess of those previously thought for auroral echoes.

Visual auroras are very rarely seen as far south as Stanford. However, a systematic study now appears possible by radio techniques. It is believed that in some respects observations at this lower geomagnetic latitude may give a more complete picture of auroral ionization than can be obtained at locations nearer the auroral zone. At Stanford, the echoes have been observed at ranges and bearings which indicate reflection from ionization at points along the auroral zone all the way from eastern Canada to Alaska.

ACKNOWLEDGMENTS

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Radio Propagation Laboratory,
Stanford University,
Stanford, California, February 20, 1954
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SOME REMARKS ON RECENT NOTES BY DRS. SUGIURA AND VESTINE

The fact noted by M. Sugiura[1] that the mean (local) hourly values of the amplitudes of SC's at Huancayo are abnormally large between 08^h and 13^h, as compared with other magnetic stations, corroborates the findings in an earlier note on this effect by the writer and H. W. Unthank.[2] As was noted by Sugiura, and also by Unthank and myself, the effect is strongly reminiscent of the abnormal S_q augmentation at Huancayo, and this suggests that it is, in part, of atmospheric origin.

In a recent note, Vestine[3] has further drawn attention to the fact that the rise in the horizontal force during the initial phase of magnetic storms at Huancayo also *appears* to be augmented relative to other stations, though the number of storms considered by Vestine is not large, and it will be necessary to analyze the

[1]M. Sugiura, J. Geophys. Res., 58, 558 (1953).
[2]V. C. A. Ferraro and H. W. Unthank, Geofisica pura e appl., 20, 27 (1951).
[3]E. H. Vestine, J. Geophys. Res., 58, 560 (1953).

initial phases of several other storms before, in the opinion of the writer, this fact can be considered to be fully established.

Because both these effects do not find an immediate explanation in terms of corpuscular theories of magnetic storms, Dr. Vestine is prompted in a further note[4] to suggest that attention should now be directed towards the formulation of a dynamo theory of magnetic storms.

Whilst there are undoubtedly atmospheric contributions to the magnetic storm currents, for instance, in the auroral zone, it is difficult to see how a phenomenon so characteristically world wide as an SC can be generated by winds in the atmosphere, started as if by a trigger mechanism. Furthermore, Meinel's observation of a Doppler-shifted H_α-line in the spectrum of the aurora, taken with the camera pointing along the magnetic lines of force, points to the entry into an atmosphere of extraterrestrial protons of high energy as the primary cause of aurorae and polar atmospheric currents.

The immediate purpose of this note, however, is to point out that, apart from Huancayo, other magnetic stations do not appear to show a daytime augmentation of the mean hourly values of the main SC impulse. On the contrary, they show a slight diminution around 08^h local time and not, as in the case of the S_q variations in middle and high latitude, a large decrease around 12^h. This is shown in Figure 1,

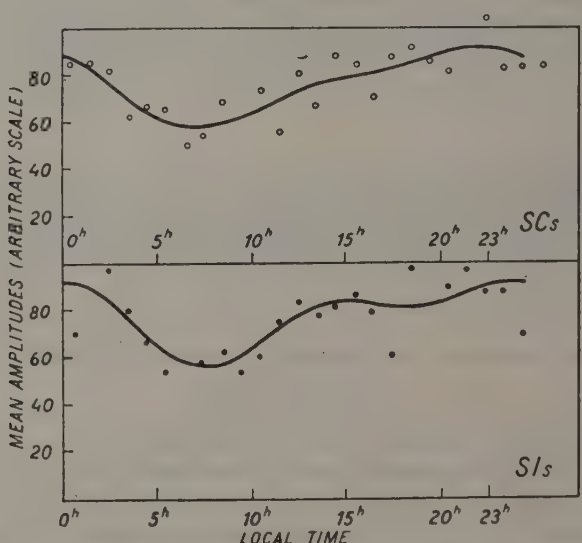

Fig. 1—"Corrected" mean amplitudes for SC's (above) and SI's (below)

which gives the "corrected" mean amplitudes of SC's for the stations Cheltenham (Md.), Tucson, San Juan, Honolulu, and Watheroo. The "corrected" means are the hourly means at each station expressed as a percentage of the mean amplitude at the five stations.

On corpuscular stream theories, an explanation is possible if one supposes that

[4]E. H. Vestine, J. Geophys. Res., 58, 539 (1953).

over the daylight hemisphere the higher conductivity in the ionosphere tends to shield the stations below from the external magnetic field produced by the stream.

Furthermore, as Dr. Vestine himself recognises, and as has been shown by Chapman,[5] Huancayo is normal as regards the D_{st} and SD parts of the geomagnetic disturbance. On a dynamo theory of magnetic storms, such as has been advocated by Dr. Oliver Wulf, this fact would be difficult to explain, since the greater conductivity over the daylight hemisphere would result in the more intense currents flowing over this hemisphere. The average characteristics of SC's and of geomagnetic storms do not, in fact, show an asymmetry as regards the day and night hemispheres, and this in itself is an argument against a purely atmospheric theory of magnetic storms.

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Department of Mathematics,
Queen Mary College (University of London),
London, E. 1, England, April 7, 1954
(Received April 12, 1954)

[5]S. Chapman, Geofisica pura e appl., **19**, 151 (1951).

NOTES

(8) *IUGG Rome Assembly 1954*—The General Secretary of the International Union of Geodesy and Geophysics has announced that the Tenth General Assembly of the Union will be held in Rome, Italy, in September 1954, the 14th and the 25th of September being tentatively suggested as the dates of the IUGG opening and closing sessions, respectively. The Union is composed of the following seven Associations: Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Physical Oceanography, Volcanology, and Hydrology. The agenda for the meetings were to have been completed by May 1, 1954. Detailed programs for the various Associations were then to be distributed.

(9) *Establishment of an Institute of Atmospheric Physics at the University of Arizona at Tucson*—Clouds as a possible untapped water resource in the arid southwest United States will be studied intensively in a scientific research program operated jointly by the University of Arizona and the University of Chicago. Establishment of an Institute of Atmospheric Physics at the University of Arizona at Tucson, initially manned by University of Chicago scientists, is aimed at determining how much the future development of dry regions throughout the world can be enhanced by efforts to stimulate additional precipitation. A group of scientists working in the field of cloud physics under Prof. H. R. Byers, Chairman of the Department of Meteorology at the University of Chicago, will organize and carry out the research work. This group has been engaged in research on clouds and thunderstorms for several years, and is doing fundamental laboratory studies and field measurements in cooperation with the U. S. Air Force. It is planned also that the new Institute will study other problems of the atmosphere, such as the possibility of utilization of solar energy received in the bright sunshine of Arizona, problems of the high atmosphere, and related topics.

(10) *The 1953 Trans-Pacific Expedition*—The fifth post-war expedition of the University of California's Scripps Institution of Oceanography returned to San Diego recently aboard the R/V *Spencer F. Baird*. Under the leaderhsip of Warren S. Wooster, scientists of the Scripps Institution spent four and a half months in oceanographic exploration of the North Pacific Ocean. The expedition was sponsored by the Office of Naval Research and the Bureau of Ships of the United States Navy. One hundred thirty-five stations were occupied in sections across the prominent permanent currents of the North Pacific and the deep Bering Sea. Between stations a continuous echo-sounding record was kept. Several new sea mounts were discovered, and numerous crossings of the Aleutian and Japan Trenches were made. The geological program also included bottom sampling by coring and dredging, and the collection of volcanic material from Bogoslof and Bayonnaise Rocks. One important outcome of the expedition was the opportunity for Japanese and American oceanographers to exchange ideas. The first American oceanographic vessel to reach Japan since the *Carnegie's* visit in 1929, the *Baird* had thousands of Japanese come aboard during her stay in Hakodate, Tokyo, and Kobe.

(11) *Radio disturbance warnings from WWVH*—The National Bureau of Standards began on January 5, 1954, the broadcast of short-term radio propagation forecasts for the North Pacific area from its standard frequency broadcasting station WWVH, the Hawaiian counterpart of the Bureau's Washington station WWV. The disturbance notices tell users of radio transmission paths over the North Pacific the condition of the ionosphere at the time of the announcement and how good or bad communication conditions are expected to be for the next 12 hours. Forecasts are prepared three times daily by the Bureau's North Pacific Radio Warning Service at Anchorage, Alaska. Currently, however, only those forecasts issued at 8 a.m. and 4 p.m. are relayed to WWVH, on the island of Maui, Territory of Hawaii. These North Pacific forecasts issued by the National Bureau of Standards apply only to short-wave radio transmission over paths that are near the auroral zone for a considerable part of their length, and supplement the more general forecasts made several days in advance. The North Pacific short-term forecasts are transmitted by WWVH in Morse Code twice each hour—9 and 39 minutes past the hour—on standard frequencies of 5, 10, and 15 Mc. Similar radio propagation warning services are provided by station WWV for communication paths across the North Atlantic at $19\frac{1}{2}$ and $49\frac{1}{2}$ minutes past the hour.

(12) *A discussion by the Royal Society pertaining to the floor of the Atlantic Ocean*—The March 18, 1954, issue (Ser. A, Vol. 222, No. 1150) of the Proceedings of the Royal Society is confined exclusively to a resume of a discussion on the floor of the Atlantic Ocean held February 28, 1953. The subject was divided into two parts: (1) problems connected with the sediments which in most places form the floor of the ocean, and (2) the problems of the deeper structure, particularly those concerning differences between oceans and continents. The seismic work in deep water is perhaps the most important improvement that has taken place in recent years in the method of studying the structure of the ocean floor. Prof. H. H. Hess, of Princeton University, discussed geological hypotheses and the earth's crust under the oceans. Recent work has determined the depth of the Mohorovičić discontinuity at sea. It is now possible to produce a hypothetical section showing the transition from a continent to an ocean, the section being consistent with both seismic and gravity results. From a comparison of geophysical results obtained at sea with those on land, Sir Edward Bullard concluded that there is a basic difference between the structure of oceans and continents, and that deep ocean basins can never have been parts of continents.

(13) *New officers, Society of Exploration Geophysicists*—The Society of Exploration Geophysicists has elected the following officers to serve beginning April 16, 1954: president, Paul L. Lyons, Tulsa, exploration manager of Anchor Petroleum Company; vice-president, Roy F. Bennett, Oklahoma City, chief geophysicist of Sohio Petroleum Company; and secretary-treasurer, Hugh M. Thralls, Tulsa, vice-president of Seismograph Service Corporation. Dr. Milton B. Dobrin, Magnolia Petroleum Company, Dallas, continues in the two-year term as editor, with Roy L. Lay, of the Texas Company and past president of the Society, to complete the 1954-1955 executive committee.

(14) *Geophysical activities of the United States Coast and Geodetic Survey*—Representatives of the Coast and Geodetic Survey conferred in Ottawa, Canada,

with officials of the Dominion Observatory on the construction of magnetic charts for 1955. Minor differences between the United States and Canadian magnetic charts along Canadian borders were adjusted, and the position of the North Magnetic Pole, determined by Canada, was adopted for use on the U. S. World Magnetic Charts—latitude 73°.8 north, longitude 101°.0 west.

Three volumes of the MHV series of publications were issued, giving magnetic hourly values and reproductions of magnetograms for 1950 for San Juan and Honolulu and for 1951 for Sitka.

Mr. *Louis Hurwitz,* Chief of the Geomagnetic Processing Section, Coast and Geodetic Survey, received the Meritorious Service Award and Silver Medal of the Department of Commerce in recognition of his work in the planning and development of practical methods of reducing magnetic records from airborne equipment to a form of data useful in magnetic cartography.

Sr. *Sergio Ferraes G.*, Chief of the Geomagnetic Department, Institute of Geophysics, National University of Mexico, visited the Geophysics Division of the Coast and Geodetic Survey for several weeks in January 1954, surveying observatory and office techniques used in geomagnetism.

(15) *Corrigenda*—In the article by E. H. Vestine in this Journal, Vol. 59, No. 1 (March, 1954, issue), on page 110, equation (10) should read "H_φ (max)/π" for "H_φ (max)". Also, same page 110, in the seventh and eighth lines from bottom of page, should read "the order $E = \omega F b^5/2a^4 \sim 5 \times 10^3$, or about 5 volts/km" for "$E = \omega F b^5/2a^5 \sim 0.5 \times 10^{-5}$, or about 10^{-13} volt/cm, and hence negligible, . . .".

(16) *Personalia*—Dr. *Felix A. Vening-Meinesz*, professor of geodesy and geophysics at the universities of Utrecht and Delft, The Netherlands, is now serving as a research consultant and lecturer at Ohio State University. He will assist on the Gravity Project of the Mapping and Charting Research Laboratory. Dr. Vening-Meinesz has been occupied for the past 30 years with the study of the earth's gravity at sea by means of measurements taken in submarines. In his underwater laboratory, he has traveled approximately 125,000 miles.

The Gold Medal of the Royal Astronomical Society has been awarded to Dr. *Walter W. Baade*, of the Mount Wilson Observatory, California, for his observational work on galactic and extra-galactic objects.

It was announced on January 15, 1954, that Dr. *Donald H. Menzel* had been appointed director of Harvard College Observatory. He had been acting director since the retirement of Dr. Harlow Shapley from the directorship in 1952.

We regret to record the death on February 7, 1954, of Dr. *Frank Wenner* at the age of 81 years. A noted physicist and seismologist, he will be remembered among his many accomplishments for his methods of measuring the salinity of sea-water and the electric unit of resistance, as well as for the precise electrical seismometer which bears his name. Dr. Wenner joined the staff of the National Bureau of Standards in 1907, where he remained until his retirement in 1943. Following this he became consulting physicist with the Carnegie Institution of Washington, the Applied Physics Laboratory of Johns Hopkins University, and the Research and Development Board of the National Military Establishment. He was recalled as a consultant to the National Bureau of Standards in 1951, where he worked on classified military projects.

Prof. *Giorgio Valle*, head of the Department of Physics and director of the Righi Institute of the University of Bologna, Italy, died suddenly last December at the age of 65. He published many papers on electric discharges, magnetism, acoustics, physical optics, and meteorology, and was author or co-author of several text-books.

We are glad to learn of the gradual recovery of Dr. *Maurice Ewing*, following the accident that befell him in being swept overboard from his vessel *Vema* while headed for Bermuda on January 13, 1954.

At the 91st annual meeting of the National Academy of Sciences, held in Washington, D.C., April 26-28, 1954, Dr. *Vannevar Bush*, President of the Carnegie Institution of Washington, was awarded the John J. Carty Medal for noteworthy and distinguished accomplishment.

Dr. *Merle A. Tuve*, Director of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, was elected a member of the Council of the National Academy of Sciences at its 91st annual meeting in Washington, D.C., April 26-28, 1954.

Dr. *Ernest H. Vestine*, chairman, Section on Statistical and Analytical Geophysics, Department of Terrestrial Magnetism, Carnegie Institution of Washington, was elected to membership in the National Academy of Sciences on April 27, 1954.

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Department of Terrestrial Magnetism,
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(Received March 31, 1954)

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